ECONOMIC GEOLOGY

VOL. XXXIV JUNE–JULY, 1939 No. 4

STRUCTURAL RELATIONS OF SOME GOLD DEPOSITS BETWEEN LAKE NIPIGON AND LONG LAKE, ONTARIO.

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ABSTRACT.

Gold is being mined at several places along a belt lying 50 miles north of Lake Superior, extending east from Lake Nipigon to Long Lake. The structural relations of the ore bodies at the following mines are briefly discussed—Northern Empire, Leitch, Sand River, Bankfield, Little Long Lac, MacLeod-Cockshutt, and Hardrock. Most of the ore bodies are in sediments. They occur in shear zones along the axial planes of minor folds, along bedding planes, along the contacts between dikes and sediments, and along the tips of tongues of porphyry stocks that intrude sediments. One vein occurs entirely in lavas.

In general the ore bodies are localized where there is considerable heterogeneity in the country rocks. Basic volcanics show considerable variation in the degree of schistosity in different parts of flows, and veins occur in schistose zones lying between massive parts of successive flows.

SEVERAL gold mines located along a belt between Lake Nipigon and Long Lake, approximately 50 miles north of Lake Superior (Fig. 1) have begun production during the past few years. Production in 1937 was approximately 90,000 oz. All of the ore bodies, excepting that at the Northern Empire Mine, have been discovered within the last seven years.

GEOLOGICAL SETTING.

A belt of sediments two to three or more miles wide consisting mainly of greywacke, arkose and slate with some beds of conglomerate, extends from Lake Nipigon eastward to Long Lake. To the north and south of it are volcanics that are apparently

the floor upon which the sediments were laid down. Both series of rocks are now closely folded so that the sediments lie as a tightly compressed syncline within the older rocks. Both series have been intruded by dikes and stocks of albitite porphyry and diorite and these in turn are cut by dikes and masses of diabase of unknown shape. Granite and granodiorite intrude the volcanics and possibly are later than the sediments, although if so there were two periods of granite intrusion, since the conglom-

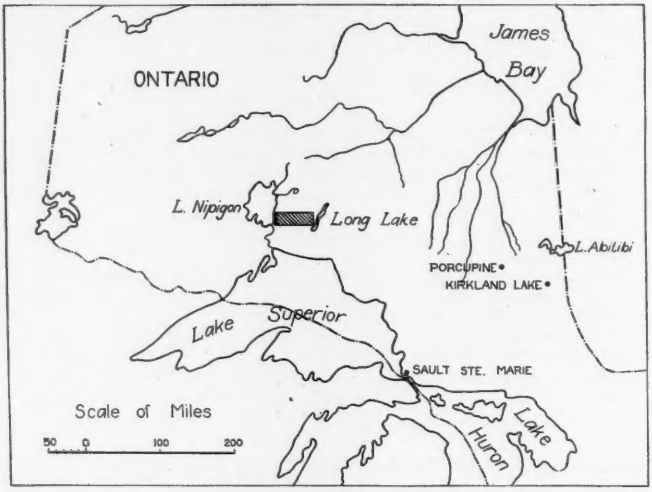

FIG. 1. Index map of Ontario.

erates of the sedimentary series contain pebbles of granite. No granite or granodiorite occur near any of the ore bodies discussed in the following pages, but some veins from which gold has been or is being produced occur in granite and granodiorite lying north of the main producing belt.[1]

Gold deposits occur in all rocks older than the diabase. The vein at the Northern Empire Mine is entirely in basic lava of the

[1] Bruce, E. L.: Eastern part of the Sturgeon River area. Ontario Dep. of Mines Ann. Rep. 45, part 2: 1–59, 1936.

oldest series. At the Bankfield Mine an albitite dike and adjoining sediments have been sheared and impregnated with some auriferous quartz; quartz veins with higher gold content traverse this low grade zone. The veins at the Little Long Lac Mine are in shear zones, nearly along the axial plane of a drag fold in the sediments. The ore bodies are confined to a bed of arkose. Some of the ore bodies of the MacLeod-Cockshutt Mine, immediately east of the Little Long Lac Mine, are partly in greywacke and iron formation intruded by tongues of albitite porphyry, partly in the porphyry adjacent to the contact. Others are along bedding planes between iron formation and greywacke and in fractured and partially replaced iron formation. At the Hardrock Mine adjoining the MacLeod-Cockshutt on the east, there are bedded veins along conglomerate, greywacke contacts. In addition on both properties certain parts of veins in a stock of albitite porphyry carry considerable gold.

DESCRIPTION OF INDIVIDUAL DEPOSITS.

Leitch and Sand River Gold Mines.

The Leitch Gold Mine and Sand River Gold Mine are situated three miles east of Lake Nipigon. Greywackes with lenses of iron formation and conglomerate lie in a great, closely compressed syncline overturned to the north and plunging to the west.

The vein at the Sand River mine is narrow. In many places it appears to be parallel to the bedding plane of the greywacke in which it lies, but the vein does not follow the bedding where the sediments are folded.[2]

Conditions at the Leitch mine are similar. The main vein is in slightly schistose greywacke on the north limb of the syncline of sediments. Part of it lies in a shear zone nearly parallel to the bedding, other parts are extremely sinuous and apparently in those places the vein follows the contorted bedding of the sediments. The average width of the vein is 15 inches, but where it doubles

[2] Laird, H. C.: Western part of the Sturgeon River area. Ontario Dep. of Mines Ann. Rep. 45, part 2: 109–112, 1936.

back on itself the width is as much as 31 inches. The vein filling is quartz, which is fractured in directions parallel to, and transverse, to the vein walls. Those parallel to the walls are the stronger and are filled with sericitic material. Along them and in the quartz near them, pyrite, tetrahedrite, sphalerite and gold occur. The cross fractures extend from wall to wall and are filled with barren white quartz.[3]

Northern Empire Mine.

The rocks in the vicinity of the Northern Empire Mine are lavas of rather basic character and dikes and irregular masses of diabase, which cut the lavas. Certain zones in the lavas are quite schistose; the planes of schistosity strike east-west and are nearly vertical. In other zones the rock is massive. Thus this oldest series has a banded character with zones of chlorite schist alternating with zones of massive, ellipsoidal-weathering greenstone in which the ellipsoids appear little deformed by the stresses that rendered the adjacent rocks highly schistose. The shapes of the ellipsoids indicate that the lavas have an east-west strike and are vertical.

The diabase is quite fresh and not at all schistose. It evidently came in long after the development of the schistosity in the lavas, since most of the dikes cut directly across the banding of the older rocks.

The vein at the Northern Empire Mine is nearly vertical. It has been followed continuously for more than two thousand feet on the surface and for 640 feet downward. At that point the shaft entered a mass of diabase, the upper surface of which is nearly horizontal. Diabase extends downward for 550 feet entirely cutting off, but not displacing, the vein, which was found beneath it.

The wall rock of the vein is chlorite schist and the vein is parallel to the schistosity. The vein is decidedly lenticular, bellying in places to widths of four feet and in other places narrowing to a mere crack. There are a few transverse faults none of which

[3] Laird, H. C.: Op. cit., pp. 103–104.

offset the vein more than a couple of feet, and some transverse diabase dikes that also cause only slight displacement. The vein filling is quartz and a small proportion of metallic minerals—arsenopyrite, pyrite and gold.

Apparently shearing movements approximately parallel to the flow surfaces produced chlorite schist along zones where for some reason the lavas were less competent. Later movements were localized along these same zones resulting in the opening up of fractures which formed channel-ways for vein-forming solutions rising from some source beneath. Subsequently, slight disturbances offset the veins in places and allowed the introduction of the diabase.

The Bankfield Mine.

The Bankfield Mine is 45 miles east of Lake Nipigon. The rocks in the vicinity of the ore bodies are conglomerate, greywacke, slates and iron formation, intruded by dikes of albitite porphyry and by irregular masses of diorite. The sediments are on the north limb of the major syncline, in which the deposits at Sand River Gold Mine and the Leitch Gold Mine occur.

The albitite dikes are nearly east-west in strike and vertical or with steep dips. Some of them are 60 feet to 70 feet in width; one mass several hundred feet in width occurs ¾ of a mile west of the Bankfield. The dike with which the ore is associated is 50 feet in width. Shearing movements along it fractured the dike itself and the adjoining greywackes, and made way for solutions that impregnated the fractured rock, both in the dike and in its walls, with quartz, pyrite, arsenopyrite and some gold. This material is low grade as a gold ore. Subsequent shearing was localized along contacts between porphyry and greywacke, diorite and porphyry or along bedding planes between dark slaty greywacke and more siliceous greywacke. In the new openings more gold was deposited, forming shoots of ore of good grade.

During both periods of disturbance formation of openings, later filled by the ores, was controlled by contacts between rocks of unlike physical character.

The Little Long Lac Gold Mine.[4, 5]

The rocks in the vicinity of the Little Long Lac Mine are mainly sediments assigned to the Timiskaming series on lithological grounds. Some small masses of diorite and narrow dikes of diabase cut the sediments but none of these intrusives outcrops near the ore bodies. The veins lie entirely in massive arkose or feldspathic quartzite so uniform that bedding can be seen in it only in a few places. The constituent minerals are quartz 40 per cent, plagioclase ($Ab_{95}An_5$) 25 per cent, sericite 15 per cent, carbonates 5 per cent, chlorite 5 per cent, kaolin 4 per cent, magnetite 2.5 per cent. The feldspar is quite fresh and evidently recrystallized. Both it and the quartz are fractured and in places sheared into lenticles.

The rock stratigraphically below the arkose is greywacke, finer grained and darker in color than the arkose, due to the presence in it of a larger proportion of chlorite. Still lower in the series are bands of iron formation. Immediately above the arkose there is a bed the thickness of which varies from 8 inches to 4 feet. It contains fragments larger than those in the arkose. Above it, the rock is massive greywacke, somewhat similar to that below the arkose. Iron formation and lenticular beds of conglomerate occur still higher in the series.

The sediments lie in a great syncline, the northern edge of which is 2,800 feet north of the shaft of the Little Long Lac mine. The axis of the syncline lies an unknown distance to the south.

Near the mine the major structure is complicated by a large drag fold. Beds followed from the east westward are found to be bent back on themselves in a reverse curve that carries them northward about three thousand feet before the regular east-west strike is resumed.

The axial plane of the anticlinal part of the drag fold is slightly curved, varying in strike from N. 88° E. to N. 80° E. The

[4] Bruce, E. L.: New developments in the Little Long Lac area. Ont. Dep. of Mines, Ann. Rep., 45, pt. 2: 118–140, 1936.

[5] Bruce, E. L., and Samuel, W.: Geology of the Little Long Lac mine. ECON. GEOL., 32: 318–334, 1937.

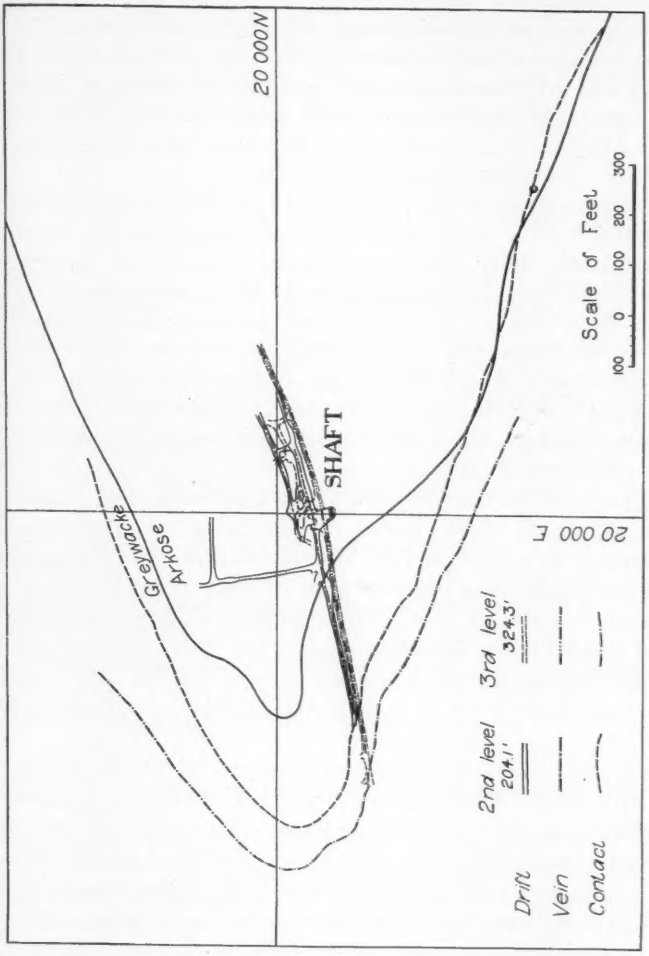

FIG. 2. Composite plan of Little Long Lac mine showing the upper contact of the arkose, and the overlying greywacke.

plunge of the fold is approximately 50° to the west (Fig. 2). Subsequent to the folding, stresses developed zones of shearing in the arkose and of schistosity in the less competent beds. The shear planes are approximately parallel to the axial plane of the drag fold. Movement along them must have been in a direction parallel to the plunging axes of the folds since the fragmental bed lying above the arkose is not offset where shear zones cross it. The major joint planes are horizontal.

The ore bodies of the Little Long Lac Mine are lodes composed of narrow quartz veins sufficiently closely spaced to make possible the mining of the intervening arkose in which the gold content is low. The main lode lies about 80 feet south of the axis of the anticlinal part of the drag fold and is nearly parallel to the axial plane of the fold. Ore bodies have been found only in the arkose since definite shear planes were formed only in that rock. The less brittle greywackes above and below were rendered schistose and so offered fewer and less continuous openings for the vein-forming solutions.

As a result, the ore zone plunges to the westward (Fig. 3), but the rake of the western end of it is somewhat steeper than the plunge of the axis of the fold since the main ore-bearing fissures are not exactly along the axial plane of the fold but lie a short distance to the south of it. The termination of the ore shoot is thus determined by the intersection of the shear zone with the contact between the arkose and the bed overlying it. The eastward extension of the ore zone is complicated by faulting (Fig. 3).

The quartz veins vary from mere cracks up to those with widths of eight inches. Commonly the major veins are flanked by small parallel veins and connected by narrow oblique ones. In places there are curved veins linking the lodes. These will be described later. In general, even the narrowest veinlets are remarkably persistent and some only a fraction of an inch wide can be traced for several feet. However, all are lenticular and any one followed far enough will be found to pinch out. However, where one veinlet ends, others commonly begin along parallel shear

planes so that the total proportion of quartz in most parts of a vein is fairly constant.

Two main zones fifty feet apart have been opened up. At places between these, curved linking veins that have the form of drag folds, diverge from one main vein zone, form a reverse curve and join the other. These folds plunge 50° to the east

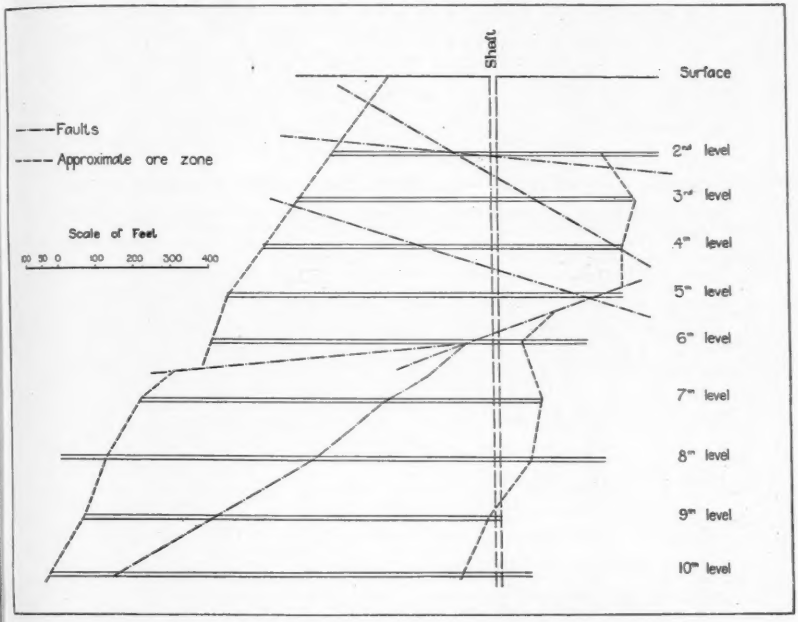

FIG. 3. Longitudinal section along the Little Long Lac vein.

rather than westerly as is the plunge of the drag fold in the sediments. Evidently these folds in the veins follow some obscure structure, probably bedding. Their shape indicates a movement of the beds on the south of the south vein zone upward and to the east, relative to the north side. This is consistent with the conclusion previously arrived at as to the direction of the movement along the shear zone in which the veins lie.

The MacLeod-Cockshutt Mine and Hardrock Mine.

The MacLeod-Cockshutt Mine lies 1¾ miles southeast of Little Long Lac Mine. The Hardrock adjoins the MacLeod-Cockshutt on the east.

The rocks in the vicinity of the ore bodies are sediments, dikes and bosses of feldspar porphyry and a few small diabase dikes. The sediments are mainly greywacke with some prominent bands of iron formation and of conglomerate. They belong to the same series as do the sediments at the Little Long Lac and Bankfield mines. The beds are approximately in the same horizon as those at Bankfield and are stratigraphically higher than those at Little Long Lac. The greywackes are dark grey and rather fine grained; some of them are well stratified. Here and there a narrow band high in hematite is present and, by increase in the number and size of these, the rock passes over into finely stratified iron formation made up of alternate bands of quartzite or of greywacke and of material high in magnetite or hematite. In places the sedimentary series contains thick lenses of conglomerate.

All of the sediments are much contorted, the iron formation to a greater extent than other types. Thickening and thinning of beds is a characteristic feature and may be seen on all scales. Less competent beds are intricately drag folded with the axes of folds plunging to the west at 30°.

A large irregular body of fairly massive albitite porphyry intrudes the sediments. Toward the margins of the mass there is a faint banding probably due to remnants of greywacke partially replaced by the porphyry as it made way for itself. The porphyry mass is an elliptical pipe from which many longitudinal fins project, mainly to the east and west along the bedding and schistosity of the sediments. The pipe plunges to the westward in a direction approximately parallel to the axial plunge of drag folds in the sediments.

Ore bodies occur in several different relations at the Hardrock Mine and MacLeod-Cockshutt Mine. Some veins occur entirely in the sediments, following bedding planes or shear planes. Such are the relations of the north ore body, which lies along the con-

tact between iron formation and greywacke. In places iron formation is fractured and ore bodies mostly of low grade have been formed by filling of fractures and partial replacement of the iron formation by quartz and pyrite. Small veins of fine-grained white quartz, containing in parts considerable visible gold, occur in the porphyry. Lenticular bodies made up of massive pyrite, some arsenopyrite, and gold in sufficient quantity to form ore bodies of good grade lie along the tips of the fin-like projections of the porphyry masses. In bodies of this type the ore is partly in the sediments, partly in the porphyry. Where the porphyry tongue is narrow its whole width may be sufficiently impregnated with auriferous pyrite to form ore.

SUMMARY.

From these foregoing descriptions, it is evident that the disturbances that prepared the way for deposition of gold-bearing quartz veins were chiefly subsequent to the folding of the volcanics and sediments, although differential movements between beds, and fractures formed in competent beds during folding, may have localized later shearing. It also seems plain that the fracturing and ore deposition were later than the periods of intrusion of all the igneous rocks excepting the diabase. The association of some of the ore bodies with dikes and stocks of porphyry is probably due entirely to the fact that the intrusive masses differed in competency from the intruded rocks and hence the fracturing was localized near the contacts.

The various conditions that have resulted in the localization of ore bodies in this area may be summarized as follows:

(*a*) Differential movements between zones of massive and schistose lava.
(*b*) Differential movements along the margins of dikes.
(*c*) Movements during which masses of igneous rocks have acted as buffers, causing fracturing in the margins of the intrusive bodies and in the adjacent intruded rocks.
(*d*) Movements localized near the crests or troughs of minor folds in sediments. These may be conspicuous only in cer-

tain favourable beds and may fade out in other beds of different character. It is evident that two conditions may arise:—

1. Fracturing may be confined to weak beds and competent beds may be unfractured.
2. Under more extreme conditions definite shear zones may develop in competent beds and may pass into zones of schistosity, unfavorable for ore deposition in weak beds.

(*e*) Bedding planes in sediments, since they are the loci of slipping along the limbs of folds, may localize later movements, so that veins will conform in a general way to the bedding.

It follows that ore bodies may result from various combinations of these conditions. Part of a vein may be parallel to bedding planes, whereas another part may occupy a shear zone that cuts across the bedding. So, too, a fracture in the margin of an intrusive mass may pass out into adjoining sediments either along a bedding plane or along a shear zone cutting across the bedding. In all cases the most favorable places for formation of ore bodies are those where rocks of different competence are in contact. The kind of rock, whether igneous or sedimentary, seems to be less important than the quality of the rock and the heterogeneity of its association.

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March 10, 1939.

COAL METAMORPHISM IN THE ANTHRACITE–CRESTED BUTTE QUADRANGLES, COLORADO.[1]

E. C. DAPPLES.

ABSTRACT.

A district in central Colorado is described in which coals of various ranks occur in a restricted area. Some of these coals have been altered by the intrusion of laccoliths whereas others have been affected only by minor folding. The individual effects of heat and pressure in the development of anthracite are discussed, and a theory of anthracitization is propounded utilizing shear strains and heat developed through friction.

INTRODUCTION.

THE problem of the origin of anthracite is one of persisting interest because of the apparently varied geological setting in which coal of this kind is found. The relative importance of the type of initial vegetation producing such coal and of heat and pressure in its formation all contribute to the problem. Regions where transition from bituminous to anthracite coals are found in relatively short distances are generally in areas of igneous activity and are not numerous. Among such areas the Anthracite-Crested Butte district of Colorado is particularly well known and provides the subject for the present discussion of anthracitization.

The setting of the phenomena to be described is the southeastern limits of the Uinta Coal Basin, a structural depression containing important deposits of Cretaceous and Tertiary coals. The Anthracite-Crested Butte area lies in a site of merging physiographic provinces, a mountainous northern half dominated by the Elk Mountain Range is separated from a southern upland extension of the Plateau Province by a series of local prominences consisting of laccolithic injections into Cretaceous and Tertiary

[1] Presented before the Society of Economic Geologists, New York Meeting, Feb. 14, 1939.

strata. Each intrusion stands as a bold, imposing, serrated projection upon the southern upland, forms a physical barrier, and thus aids in subdividing the district into simple geographic units that have been called the Mount Carbon, Floresta, and Slate River Valley coal fields.[2]

Scope of the Study.—The relationship of the coal fields in the Anthracite-Crested Butte quadrangles to igneous intrusions gives the area importance in the study of the thermal metamorphism of coal. The inquiry involves two lines of investigation as follows:

1. The evaluation of the effect and the relative importance of intrusion and pressure in the various coal fields where thermal metamorphism has evidently taken place.

2. The interpretation of anthracitization in an area evidently remote from thermal effects arising from intrusion.

Acknowledgments.—The writer wishes to acknowledge the helpful counsel, in these studies, of Dr. G. H. Cady, Dr. C. H. Behre, Jr., and Dr. W. H. Twenhofel. The U. S. Bureau of Mines kindly furnished analyses of the coals of the area. Messrs. F. H. Klaer and C. C. Sprague ably assisted in the field work.

SEDIMENTARY ROCKS.

The coal bearing strata that form part of the Mesaverde formation consist of the following five lithologic types. Among each there is a wide degree of variation in facies due to lateral lithologic changes in the individual units or to interfingering of different units:

(1) Massive sandstone.
(2) Gray and olive-drab sandy shale.
(3) Black shale.
(4) Olive-drab sandstone.
(5) Coal and underclay.

Examination has failed to reveal a similarity in the sequence of these units indicative of regular cyclical deposition. Therefore,

[2] Lee, W. T.: The coal fields of Grand Mesa and the West Elk mountains, Colorado. U. S. G. S., Bull. 510, 1912.

the original subdivision of the Mesaverde as erected by Lee,[3] with certain exceptions, have been adhered to as follows:

Mesaverde formation:
- Undifferentiated Mesaverde,
- Paonia shale member,
- Bowie shale member,
- Rollins sandstone member.

Strata near the village of Baldwin that Lee identified as Bowie, the present writer believes underlie the Rollins sandstone forming part of a new member called the Baldwin sandstone, the Bowie being generally absent. Hence the writer proposes the following classification:

Mesaverde formation:
- Upper Mesaverde,
- Paonia shale member,
- Rollins sandstone member,
- Baldwin sandstone member.

Coals appear in the Baldwin, Paonia, and upper Mesaverde members as indicated below:

Upper Mesaverde	Ruby coal, coal no. 4.
Paonia shale	Smith Hill coal,
	Peanut coal,
	Coal no. 2,
	Bulkley coal.
Baldwin sandstone	Seven coal beds of local occurrence.

IGNEOUS ROCKS.

Igneous rocks of remarkably similar appearance compose the laccolithic bodies and their associated dikes and sills. Regional variation in the rocks is no greater than local variation, so that a single description suffices for all the igneous rocks involved in coal metamorphism.

The rock is prevailingly a light gray, rather coarse-grained quartz monzonite of porphyritic texture with phenocrysts of

[3] Lee, W. T.: Op. cit.

quartz and orthoclase. No highly chilled contact zones were observed other than those of the sills in the Anthracite Range.

Euhedral crystals of glassy orthoclase up to 1 to 2 inches long are probably sanidine. Small crystals of orthoclase in the ground mass are associated with andesine and some quartz, which is generally in rounded grains. The andesine crystals are commonly highly zoned and euhedral, but they are likewise commonly deeply indented, corroded, and replaced by stilbite. Altogether the andesine composes about 25 per cent of the volume of the rock. Tabular crystals of biotite represent 10 per cent, and hornblende in accicular and well terminated crystals about 15 per cent of the rock.

Close genetic relationship of the laccoliths and a similar history subsequent to intrusion is suggested by the similarity of the rocks of the different porphyry masses in the area. No differentiation in situ has taken place in any of the masses. Alteration through the development of zeolites from andesine and resorption of quartz is the same in all the laccoliths, and, finally, all intrusions are of the same shallow depth type evidenced by prominent zoning of plagioclase and the fine-grained groundmass.

STRUCTURAL RELATIONSHIPS.

Regional Structure.—Except for the irregularities mentioned below, coal-bearing strata in the Anthracite-Crested Butte quadrangles have gentle dips of 3–10° SW. Departures from such gentle inclinations are as follows (Fig. 1):

1. A prominent north-south trending monocline whose western limb dips at an angle of 20° borders the edge of the coal basin. The structure is best seen along the outcrop of the Mancos shale and Mesaverde formations.

2. A southwest plunging syncline (Coal Creek Syncline) strikes transversely to, and strongly warps, the western limb of the monocline described above.

3. Local arching of strata up to 30 degrees is restricted to the flanks of laccolithic intrusions.

The monocline parallels, and forms a part of, the Elk Mountain folding to the east, whereas the Coal Creek Syncline parallels

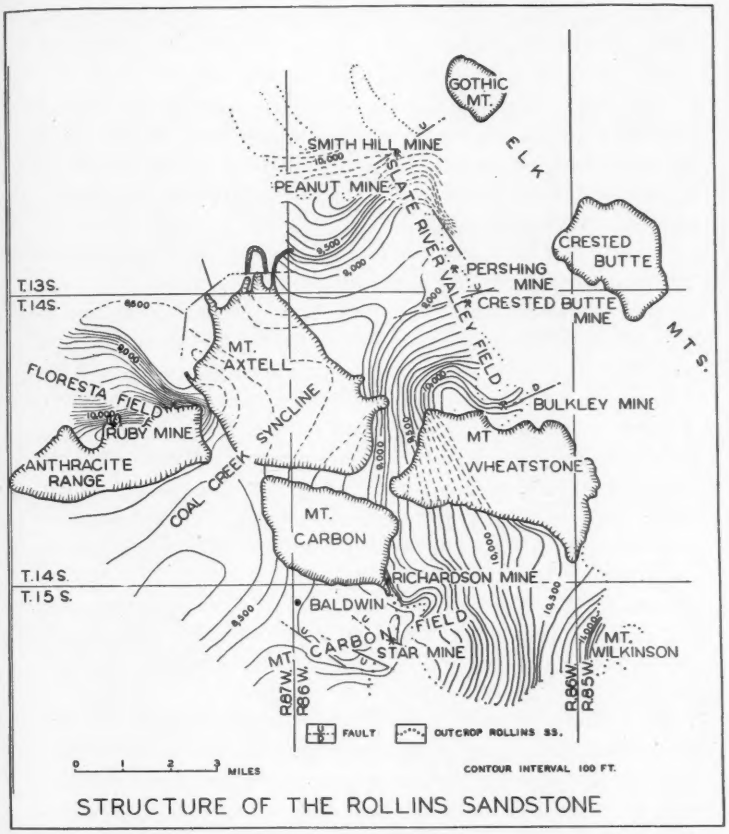


FIG. 1. Structure of the Anthracite-Crested Butte coal district based upon structural contours on the top of the Rollins sandstone.

other nearby structural features that strike transversely to the Elk Mountain folding and which Burbank [4] has shown constitute a major structural feature extending from the Front Range to the San Juan Basin.

[4] Burbank, W. S.: Relation of paleozoic and mesozoic sedimentation to the cretaceous-tertiary igneous activity and the development of tectonic features in Colorado. Ore deposits of Western United States. A. I. M. E., p. 287, 1933.

The Coal Creek syncline has little plunge and is best seen in cross section in the Slate River Valley just north of Crested Butte where the north limb is observed to dip 10 to 20°.

Laccolithic intrusion and its consequent arching of strata is distinct from the folding already mentioned since arching along the north limb of the Anthracite Range, the west limb of Mount Carbon and the north flank of Mount Wheatstone is discordant to the Coal Creek Syncline.

Structure of the Large Igneous Masses.—Mount Marcellina in the west part of the Anthracite quadrangle, regarded by Cross [5] as typical of the laccoliths of the district, is described by him as consisting of an igneous mass, which during its intrusion bowed the strata on its northern flank to produce a sharp dip and the appearance of conformability with the igneous rock. Actually, however, the injection transgresses at least 1,000 feet of strata extending from the Mancos into the upper Mesaverde. On the southern side, the strata are not upturned but abut sharply against the intrusion. Mount Marcellina represents laccolithic injection somewhat imperfectly but the departures from regularity are so consistent as to characterize a definite type (Fig. 2). Within the quadrangle four other mountains, Carbon, Wheatstone, Axtell and the Anthracite Range are almost identical counterparts of Mount Marcellina in the characteristic intrusive structure displayed.

No evidence of marked plasticity of strata indicative of deep seated intrusion exists in the Anthracite-Crested Butte region.[6] Soft shales show no distortion and sandstones are commonly highly fractured. Coal beds that might be expected to show evidence of plastic movement, display no distortion of the banded ingredients except in one small area. Hence, it appears the coal beds did not behave as a quasi-solid substance. Adjustment in the sedimentary beds must, therefore, have taken place under a load insufficient to produce plasticity. Further evidence that

[5] Cross, Whitman: The laccolithic mountain groups of Colorado, Utah, and Arizona. U. S. G. S., 14th Ann. Rpt.: 183–184, 1894.

[6] Gilbert, G. K.: Report on the geology of the Henry mountains. U. S. Geog. and Geol. Surv. of the Rocky Mt. region, p. 90, 1880.

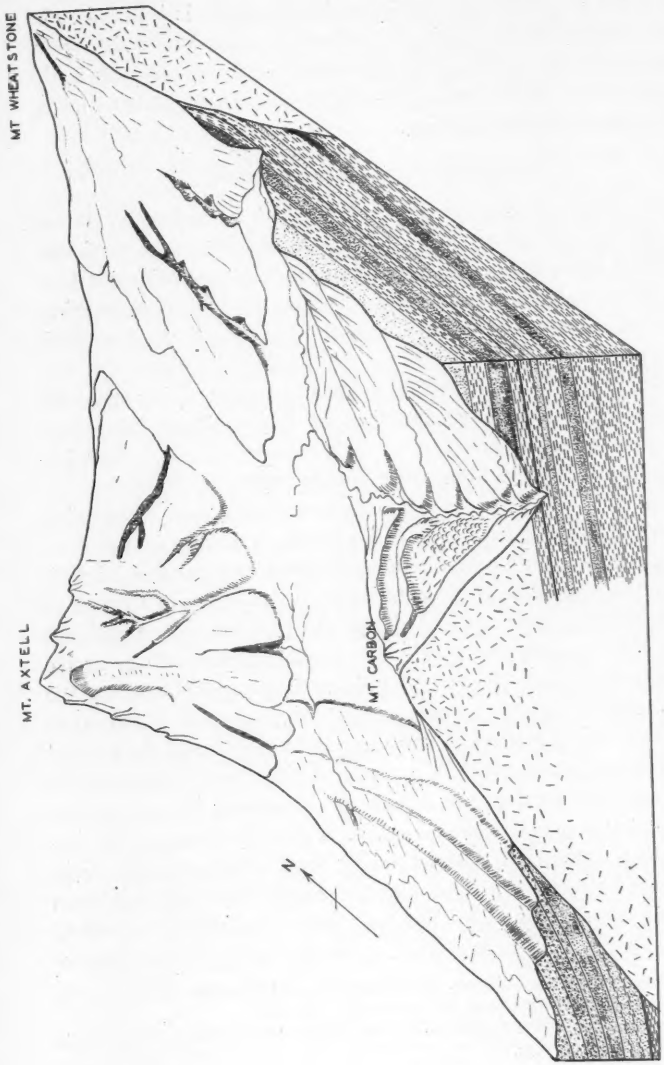


FIG. 2. Diagrammatic structure of the Mount Carbon laccolith.

intrusion occurred at a relatively shallow depth is believed to be furnished by the fine grained interlocking groundmass of the porphyries, by the zoned andesine crystals, by the narrowness in the sediments of the contact zone of thermal metamorphism, and by the common border faulting.

TEMPERATURES OF INTRUSION.

The extent to which the heat of laccolithic intrusion contributed to the metamorphism of the coal in the district is the particular problem under investigation. An estimate of the maximum temperature available for such metamorphism depends upon the thickness of cover, geothermal gradient, and heat of the laccolithic masses.

Thickness of Strata.—The sedimentary cover lying upon the Mesaverde formation at the time of laccolithic intrusion consisted of at least 5,700 feet of early Tertiary strata. An additional 1,000 feet of Mesaverde beds lay upon the Ruby coal, resulting in a minimum of 6,700 feet of sedimentary cover lying upon a single coal horizon. If the porphyry bodies are late Tertiary in age, then an additional thickness of 10,000 feet of sediments may have been present.[7] The latter figure is selected as the uppermost limit of the thickness of late Tertiary material that may have covered the porphyries despite its probable excessive magnitude. Thus the variation in sedimentary cover over the porphyries is believed to have ranged from 6,700 to 17,000 feet.

Geothermal Gradient.—Van Orstrand[8] shows that the normal geothermal gradient within a sedimentary series lies between 60 and 110 feet per degree Fahrenheit. Assuming the present average annual temperature of 40° F. as that obtaining in the Anthracite-Crested Butte district during the Tertiary, and the thicknesses of strata mentioned above, the maximum and minimum temperatures attained by the coal due to geothermal gradient ranged between 38° and 162° C. During the time of the igneous

[7] Behre, C. H., Jr., and Powers, W. E., have informed the writer that 10,000 feet of late Tertiary sediments occur in South Park, Colorado.

[8] Van Orstrand, C. E.: Normal geothermal gradient in the United States. A. A. P. G., Bull. 19: 114, 1935.

activity the geothermal gradient may have more closely approached 60 feet rather than 110 feet per degree Fahrenheit. Assuming a gradient of 60 feet per degree the range in temperature would be reduced to between 67° and 162° C.

More definite limitation to the permissible temperature range is furnished by the waxes which are found in the lower rank coals of the region. Yellow and brown waxes are found, the former melting at 193–210° C. under atmospheric pressure. Yellow wax when held at a temperature near 165° C. in the air becomes dark brown and eventually powders. Some waxes from the Peanut and Bulkley coals are brown, but never powdery, hence it is thought that these coals never attained a temperature of 165° C. On such a basis the geothermal gradient resulted in temperatures in the coal bed that were in excess of 67° C. but which were less than 165° C., or in round numbers, between 70° and 150° C.

Heat from Igneous Masses.—Lovering[9] has suggested a method of computing the temperatures attained by the country rock during the interval of cooling of a spherical laccolith one kilometer in radius (approximately that of the Anthracite Range). Following his procedure it has been estimated that the maximum temperature reached at the horizon of the Ruby coal (300 feet above the intrusion) would be .27 θ, θ being the initial temperature differential. This result assumes that diffusivity and conductivity are the same in the wall rock as in the igneous mass. As previously explained, the initial temperatures of the wall rock are believed to have ranged between 70° and 150° C. and the temperature of the porphyry at the time of intrusion is considered to have approached Larsen's[10] estimate of the average for rhyolitic lavas, approximately 900° C. The temperature differential, θ, may, therefore, be considered to have been 750° to 830° C. and .27 θ is 200° to 225° C., respectively. Such figures added to the original temperature of the wall rock give temperatures of between 350° and 295° C., respectively, as the approximate maxi-

[9] Lovering, T. S.: Theory of heat conduction. G. S. A., Bull. 46: 78, 1935.

[10] Larsen, E. S.: The temperature of magmas. Am. Min., 14: 88, 1929. Larsen's estimate is 870° C.

mum temperatures attained by the Ruby coal following the porphyry intrusion.

METAMORPHISM PRODUCED BY THE INTRUSIONS.

The clastic sedimentary rocks of the area associated with the coals are unresponsive to low temperature metamorphism and alteration of such rocks is scarcely noticeable megascopically other than by a thorough silicification of a thin envelope of sediments immediately adjacent to the igneous masses. In the Anthracite Range the silicified zone is about 100 feet wide, the shales being spotted, and locally altered to hornfels. Zeolites appear near the intrusions but no minerals indicative of higher temperatures have been found. Deuteric alteration of the porphyries is almost negligible, appearing as zeolitization of the andesine and resorption of the quartz. The observed evidences of slight thermal metamorphism accord with calculated temperatures attained by the Ruby coal as explained above.

COAL BEDS OF THE DISTRICT.

General Structural Features.

Each of the basins such as the Mount Carbon, Slate River Valley, and Floresta fields isolated by the laccolithic uplifts contain coal beds.[11] Those of the Mount Carbon field are practically horizontal; dips do not exceed 10 degrees, except on the western flank of the laccolith. Strata in the Slate River Valley field are somewhat more inclined, their dips approaching 20 degrees but over a considerable area their attitude approaches horizontality. In the Floresta field the strata uniformly dip as a single block 25 to 30 degrees.

Rank of the Coals.

In the Mount Carbon field, coals vary in rank from subbituminous A to high volatile bituminous C group according to the classification by rank adopted by the American Society for Test-

[11] Lee, W. T.: Coal fields of Grand Mesa and the West Elk mountains, Colorado. U. S. G. S., Bull. 510, 1912.

ing Materials.[12] Coals of the Slate River Valley field vary from anthracite to high volatile bituminous B group, whereas in the Floresta field the coal is restricted to the anthracite rank. Locally, as will be explained, the coal in the Floresta field has been coked in contact zones.

Subbituminous A Group Coals.—Coals that seem to occur particularly in the Baldwin sandstone and at the outcrops have the appearance of low rank subbituminous coals are those of lowest rank within the area. In thin section the duller bands, commonly 3 to 4 millimeters thick, are seen to be composed of a resinous translucent clarain somewhat massive and containing only small quantities of "opaque matter" considered by Thiessen [13] to be formed by a high degree of decomposition of wood fibers. Vitrain is present in bands that vary from 2 to 4 millimeters in thickness and contains considerable resinous and waxy material. Fusain is not uncommon and consists largely of the resistant vascular bundles of plants.

Another occurrence of subbituminous coal is in the Peanut bed near Baldwin. Megascopically this coal appears to be quite similar to the coals in the Baldwin sandstone yet microscopically it is somewhat dissimilar since the clarain of the former is micro-laminated and contains considerable "opaque matter."

Bituminous High Volatile C Group Coals.—With the exception of the local occurrence of subbituminous coal mentioned above the remainder of the Peanut bed in the Mount Carbon field may be classified as of high volatile C group rank. Much of the coal is composed of micro-laminated clarain, the banding consisting of alternating thin bands of vitrain, "opaque matter," and clarain, but occasional lenses of vitrain 3–4 millimeters in thickness occur. The thin laminae are commonly contorted around oval-shaped resinous bodies 1/100 millimeter in diameter, which constitute a part of the resinous cells residual from the original wood.

[12] Tentative specifications for classification of coals by rank. Am. Soc. Test. Mat., Designation D 388-34T, 1934.

[13] Thiessen, Reinhardt and Sprunk, G. C.: The origin of finely divided or granular opaque matter in splint coals. Fuel in Sci. & Prac., 15: 304–315, 1936.

Bituminous High Volatile B Group Coals.—Coals occurring in the southern part of the Slate River Valley field belong to the high volatile B group. Such coals have a well developed cleat and consequently form more regularly shaped lumps than coals from the Mount Carbon field. Nevertheless, they have much the same appearance as the lower rank coals and consist chiefly of units of micro-banded clarain 15–20 millimeters in thickness and bands of vitrain 2–4 millimeters thick. A few lenses of fusain generally not more than one millimeter thick occur with sufficient continuity to furnish planes along which the coal breaks when mined. Waxes common in the Peanut coal of the Mount Carbon field are somewhat less abundant in the high volatile B group coals.

Semi-anthracite Coals.—Several coals including the Bulkley, No. 2, and Peanut become semi-anthracites immediately north of the axial plane of the Coal Creek syncline northwest of Crested Butte. Coal of such rank is inclined with other strata at angles not exceeding, and generally less than, 5 degrees. The change from bituminous to semi-anthracite is accompanied by distinct changes in the appearance and behavior of the coal manifested particularly in an increase in hardness and a brilliant sub-metallic luster. Banding, although thin, is largely subdued except for a few massive streaks of vitrain that may exceed 15 millimeters. Despite such striking bands the chief constituents are finely laminated bands of clarain alternating with bands of durain. The latter consists of lenses of vitrain imbedded in granular "opaque matter" containing 13 to 33 per cent ash.

Fracturing of minor intensity is a feature characteristic of the semi-anthracites and higher rank coals. In the semi-anthracites the movement has commonly produced only a polishing of the surface of the break with consequent destruction of the appearance of banding. In other instances adjustments to pressure have resulted in a closely spaced cleat averaging 4 or 5 fractures to the centimeter and cutting the banding at an angle of approximately 70 degrees. Such cleats occurring in two directions striking roughly at right angles to one another produce an uneven, hackly surface on the coal.

Anthracite Coals.—Anthracites are found in all three fields, associated with the laccoliths in the Mount Carbon and Floresta fields and with the north limb of the Coal Creek syncline in the Slate River Valley field. The single occurrence of anthracite in the Mount Carbon field is beneath the floor of Mount Carbon where the Peanut coal, which outside the periphery of the intrusion is a high volatile C group coal, has been raised in rank. Anthracitization has produced uniformly grayish black, submetallic luster, slickensided surfaces, and a peculiar grooving resulting in a structure resembling cone-in-cone. There has also been an increase in hardness and a general similarity in luster between vitrain and clarain bands. Fusain within the anthracite, as in the bituminous coal, remains fibrous and rather soft.

Resins and waxes, that are so abundantly distributed within the coals of the Mount Carbon field, are completely absent from the clarain of the anthracite. But, there are cavities now filled with mineral matter, which in size and shape are identical with those containing resinous substances in the bituminous coal. It is the writer's belief that the inorganic material has filled voids left by volatilization of the resins.

Physical and chemical anthracitization appears to have proceeded to a greater degree under the laccolith than near its edge. Greater compaction, less friability, less evident banding, and an absence of shrinkage cracks characterizes the higher rank coal as indicated by the higher fixed carbon values (moist, min.-matter free basis). The actuality of compaction is indicated by a decrease in the thickness of the bed from 4 feet where it is of bituminous rank to 3 ft. 8 in. and 2 ft. 10 in. in the Richardson mine beneath the laccolith, a decrease of from 10 to 30 per cent.

Anthracite in the Slate River Valley field occurs where the north limb of the Coal Creek syncline dips at angles approaching 20 degrees, north of the area of semi-anthracite. In this locality the Bulkley, Peanut, and Smith Hill coals are all anthracites and are quite similar in appearance. The coals have rather brilliant grayish black, sub-metallic lusters, break with conchoidal fracture into angular fragments, and have suffered considerable fracturing

of minor magnitude within the stratum as indicated by grooving and slickensiding of fragments.

Much of the description of the anthracites of the Slate River Valley is suitable for the Ruby anthracite of the Floresta field, but the Ruby coal exceeds in brilliance and hardness. The coal bed is closely fractured, the surfaces of the fracture planes being either highly polished or gouged by a series of closely spaced (1–2 mm.) scratches. Microscopic examination of polished surfaces revealed a brilliant surface unmarked by traces of organic structure even after etching with chromic acid. The existence of attrital bands was suggested only by the presence of occasional detrital mineral matter and shreds of fusain. The latter, alone, showed any trace of organic structure. No honey yellow resin grains or veinlets of wax were observed, nor were there any indications that they had originally been present. If such material had been present presumably it has been volatilized and the openings closed during the process of anthracitization.

Natural Coke.

Natural coke is found in two localities in the Floresta field. In one instance it occurs in the abandoned Ruby mine but fragments of coke and porphyry in contact have been recovered from the mine dump. The other locality is an outcrop where the Ruby coal is upturned on the flanks of the Anthracite Range. The coked zone is apparently 3 to 4 feet in width, the entire zone being only partially exposed. Much of the coke has the appearance of the artificial variety having a distinctly sub-metallic luster, gray color, and porous texture. Pore space seems to be chiefly the result of thorough fracturing into small angular fragments rather than vesiculation (Fig. 3). Nevertheless, vacuoles appear on polished surfaces profusely scattered throughout the coke. Such surfaces also clearly reveal its brecciated nature as crushing appears to have taken place during the coking process. Individual fragments were later recemented together by coaly material rendered fluid during the heating by the porphyry. Much of the cementation, however, was incomplete so that the coke is very

friable and may be broken with ease between the fingers. Additional physical breakdown is brought about by larger, more continuous fractures which by their slickensided surfaces indicate a later time of development than the smaller, partly cemented, fractures. Individual fragments of the coke breccia reveal no vestige of banding, the material appearing uniform except for the occasional pieces of fusain. Apparently such changes as were effected by the porphyry upon the fusain failed to destroy the latter's cellular structure easily recognized microscopically. In the hand speci-

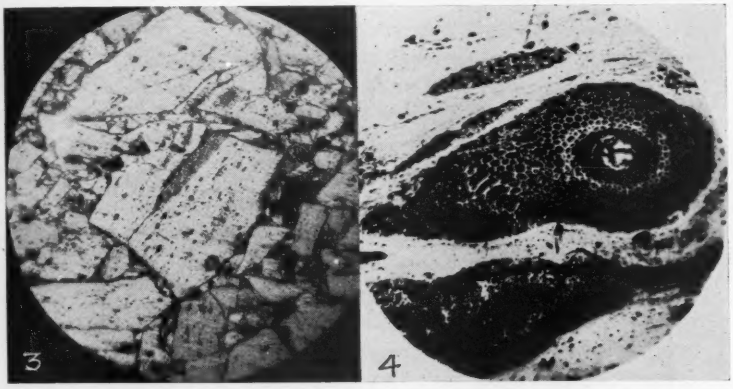


FIG. 3. Polished section of the Ruby coke. Note the fragmentation and re-cementation of particles. The black spots are vesicles developed during the heating. (50 ×.)

FIG. 4. Fusain in the Ruby coal showing uncrushed lumens of cells. In the bituminous coal such lumens are nearly always filled with wax deposited after coalification. Such lumens are always empty in the anthracites. (100 ×.)

men, however, the fusain is indistinguishable from other constituents of the coke.

COAL METAMORPHISM.

There is a lack of agreement concerning the relative and actual effectiveness of pressure and heat in the metamorphism of coal. The theories of Campbell, White, and Thiessen place much im-

portance on the weight of sediments and tangential pressure. The "Carbon Ratio" theory of progressive metamorphism advanced by White has received more recent support by Turner,[14] Stadnichenko,[15] and Hendricks.[16] Hickling[17] reasons that it is extremely improbable for temperatures approaching 500° C. to exist in the development of anthracites because field evidence indicative of such temperature is lacking. He believes the temperature never exceeded 200° C., with 150° C. probably nearer the maximum.

Those who regard heat as essential for coal metamorphism include Gropp and Bode,[18] Erdmann,[19] and Elvett Lewis.[20] Gropp and Bode maintain that temperature is more vital than pressure. Erdmann believes bituminous coal develops at temperatures ranging from 300–325° C. and Lewis holds that temperatures of 450–500° C. are essential for the formation of anthracite.

Semi coke (low temperature coke) provides one source of information concerning temperatures that obtain during coal metamorphism. When such material is re-heated volatile matter is not released until the temperature exceeds that reached in the initial carbonization. Roberts[21] believes the temperatures of volatilization and exothermic reactions of coals of different ranks likewise are indicative of the temperature of previous heating, and hence that anthracites have been subjected to temperatures ranging from 500–550° C. Roberts also considers great pressure as

[14] Turner, H. G.: Anthracites and semi-anthracites of Pennsylvania. A. I. M. E., Trans. (coal div.), 108: 330–341, 1934.

[15] Stadnichenko, Taisia: Progressive regional metamorphism, lower Kittanning coal bed, Pennsylvania. Econ. Geol., 29: 511–543, 1934.

[16] Hendricks, T. A.: Carbonization in part of Arkansas-Oklahoma coal field. A. A. P. G. Bull. 19: 937–947, 1935.

[17] Hickling, George: The properties of coals as determined by their mode of origin. Coll. Guard., 144: 481, 1932.

[18] Gropp, W., and Bode, H.: Uber die Metamorphose der Kohlen und das Problem der Kunstlichen Inkohlung. Braunkohle, 31: 277–284, 299–302, 309–313, 1932.

[19] Erdmann, E.: Der genetische Zusammensetzung von Braunkohle und Steinkohle auf Grund neuer Versuche. Brennstoff: Chemie, 5: 177–186, 1924.

[20] Lewis, Elvett: Discussion on: Hickling, George: The properties of coals as determined by their mode of origin. Coll. Guard., 144: 481, 1932.

[21] Roberts, John: Low temperature origin of anthracite. Pan Amer. Geol., 48: 40, 1927.

a necessary agent to anthracitization. Lessing [22] considers a more moderate temperature of 300° C. is adequate to produce anthracite since cellular structure is not developed.

Much field evidence supports those claiming that high temperature is essential for anthracitization in areas where coal beds are in contact with intrusive masses. McFarlane [23] from observation of contact phenomena concludes that anthracite formed at temperatures of 600° C. and semi-anthracite (F. C. 90.9–95 per cent) formed between the range of 350–600° C. At Meissner, Germany, a lignite intruded by basalt produced two types of coal, a lignitic dull type (V. M. 38 per cent) and a brilliant "anthracite" (V. M. 17.5 per cent) both varieties being intercalated with unaltered lignite. Le Graye [24] believes such coal must have been subjected to temperatures near 350° C. Somewhat lower temperatures are attributed by Zwierzycki [25] to be adequate for anthracitization of certain coals in the Dutch East Indies. The coals are metamorphosed by andesite sills, coke being produced where temperatures reached 600–900° C. and anthracite at temperatures of 160–350° C.

Contact metamorphism is clearly competent to effect anthracitization, at least on a small scale. Whether extensive anthracitization of a bed or group of beds can be accomplished by pressure alone, that is, without the aid of heat sufficient to volatilize the coal under atmospheric pressure, is uncertain. It is proposed to examine the relationships existing in the Anthracite-Crested Butte quadrangles to determine whether or not they will illuminate this uncertainty.

[22] Lessing, R.: Conversion of bituminous coal to anthracite. Gas. Jour. (London), 198: 132, 1932.

[23] McFarlane, G. C.: Igneous metamorphism of coal beds. ECON. GEOL., 24: 10, 1929.

[24] Le Graye, M.: Anthracitisation par metamorphisme de contact. Soc. Geo. de Belge, Ann., 53: 1376–1377, 1930.

[25] Zwierzycki, J.: Die Metamorphose van Kolen. De Mijningenieur, 11: 124–25, 1930.

THERMAL AGENCY IN COAL METAMORPHISM ANTHRACITE-CRESTED BUTTE DISTRICT.

Temperature Ranges of Coke Formation.

The temperatures necessary to produce coke under natural conditions may be estimated by application of Lovering's [26] equations and charts to the relationships observed in areas where coke has been observed in the Anthracite Range. Although the zone representing the complete gradation from coke to anthracite is not visible the thickness of the coked zone can be determined within certain limits. A granite porphyry apophysis approximately 200 feet wide produced a coked zone between 3 and 4 feet wide. By the method proposed by Lovering the temperature at the contact of a dike of the above thickness and coal bed may be calculated to be 77 per cent of the difference between their respective initial temperatures added to the initial temperature of the coal bed. If as previously stated the temperature of the intrusion was about 900° C., and the initial temperature of the coal ranged between 70° and 150° C., the temperature differential was 750° to 830° C., 77 per cent of which is 578–639° C. Such an increase above the initial temperature of the coal bed would result in a maximum temperature of coke formation of 709° to 728° C. or of the order of 700° C., in round numbers. Applying Lovering's [27] charts to the problem, the temperature 4 feet from a dike 200 feet in thickness is 47 per cent of the temperature differential between the wall rock and the dike or, 350–390° C. Such figures added to the initial coal temperature give 460–500° C. as the minimum temperature of coke formation. Coke in the Ruby coal was therefore thought to have developed at temperatures ranging from 460° to 500° C., figures that are considerably lower than those given by Zwierzycki.[28]

[26] Lovering, T. S.: Heat conduction in dissimilar rocks and the use of thermal models. G. S. A., Bull. 47: 87–100, 1936.

[27] Lovering, T. S.: Theory of heat conduction applied to geologic problems. G. S. A., Bull. 46: 76, 1935.

[28] Zwierzycki, J.: Op. cit., p. 124–125.

Laboratory Coking Temperatures.

Thiessen and Sprunk[29] found that in heating small blocks of West Virginia coal (high volatile bituminous A group) coking was initiated as low as 350° C. By application of the procedure described by Thiessen and Sprunk two blocks of coal from the Anthracite-Crested Butte district, one a high volatile bituminous B group from the Crested Butte mine, and the other a high volatile bituminous C group from the Star Mine were similarly heated to 350–380° C. Decompositon began slightly above 350° C. and large vacuoles developed at temperatures between 350° C. and 380° C. Such results suggest that for high volatile bituminous coals, in general, coking is initiated at temperatures which are of the same order of magnitude and are less than 400° C. under atmospheric pressures. Under pressure, however, vacuoles do not develop at such low temperatures as shown by Roberts[30] and, therefore, under a heavy blanket of sediments vacuoles should develop at higher temperatures than those observed under atmospheric pressure. If such is the case the temperatures of coke development in the Ruby coal as calculated by means of Lovering's curves are probably not excessive.

Temperature of Anthracitization.

Ruby Coal.—The absence of vesiculation in the Ruby coal bed as a whole indicates that although temperatures of 295–350° C. may have developed, the temperature did not reach 460–500° C. A minimum temperature at the base of the coal is established by the presence of stilbite known to form near 100° C.[31] Waxes known to melt near 200° C. are entirely absent from the Ruby bed, hence the temperatures must have exceeded the minimum. The absence of resinous substances appears to demand temperatures higher than their melting points for they appear to have

[29] Thiessen, Reinhardt, and Sprunk, G. C.: The effect of heat on coal as revealed by the microscope. Fuel in Sci. and Prac., 13: 116–124, 1934.

[30] Roberts, John: Conversion of bituminous coal to anthracite. Gas. Jour. (London), 198: 193, 1932.

[31] Doelter, C.: Handbuch der Mineralchemie, band II. (3) p. 14, 1921.

been volatilized. The fact of volatilization of the resins in the Ruby coal is established by the presence of empty, yet uncrushed, cell lumens that normally contain resins (Fig. 4). If removal of the resins by squeezing had been important the cell walls

FIG. 5. Drag folds in the Ruby coal. Note the brecciation and recementation of the banded constituents. (½ ×.)

FIG. 6. Outcrop of the Ruby coal bed (Floresta Canyon) showing massive sandstone that has sheared the top of the coal bed. The Ruby coal lies between the hammer handle and the sandstone layer.

should be crushed. The approximate actual temperature between the minimum of 100° C. and the maximum of 500° C. for the following reasons is believed to have been about 350° C.

1. The local development of coke occurred only where the temperature reached 468–700° C.

2. From Lovering's [32] chart it may be determined that heat dissipation from the Anthracite Range laccolith would result in temperatures varying from 295–350° C. at the base of the coal.

3. The entire removal of resins from the anthracite by volatilization would require a temperature of 350–380° C. under atmospheric pressure.

4. Small drag folds developed locally in the coal, but not in the associated beds, suggest that the coal, particularly the vitrain bands, acquired slight plasticity although heated insufficiently to initiate vesiculation (Fig. 5).

Peanut Coal.—Localization of the anthracitized coal to a position contiguous to the Mount Carbon porphyry body is in itself irrefutable evidence of metamorphism by heat. The presence of vacuoles within the anthracite and not in the adjacent bituminous coal indicates that temperatures sufficient to initiate coking had affected the now anthracitized coal. It does not follow, however, that the volatilization evidenced by vesiculation was necessarily a process accompanying anthracitization. Vesiculation may have followed anthracitization provided the volatile content of the anthracitized coal was sufficient. The combined volatile matter and moisture content of the Richardson mine (Peanut) coal is between 8 and 11 per cent; of the Ruby coal 12 per cent (volatile matter alone); bituminous coal from the same bed as the Richardson mine anthracite averages 45–50 per cent combined volatile matter and moisture. Pursuing this line of reasoning it became important to know whether experimentally anthracite with 12 per cent of volatile matter would develop vacuoles when heated to coking temperatures. Consequently, seven blocks of freshly mined Ruby anthracite ½ in. × ½ in. × 1 in. were heated in open and closed crucibles individually to 350°, 450°, 550°, 650°, 750°, 850°, and 950° C. respectively. Each block was held at the end temperature to which it was heated for ½ to 2½ hours, the time decreasing as the temperature increased. Those heated in

[32] Lovering, T. S.: Theory of heat conduction applied to geologic problems. G. S. A., Bull. 46: 78, 1935.

the open crucible ignited above 350° C., but the coal showed no effects other than the ashing of the surface. The blocks heated in closed crucibles at temperatures of 750°, 850°, and 950° C., for a period of ½ hour were subsequently polished on one side for microscopic study.

The visible effect of heating upon the blocks consisted in the development of cracks, first in the vitrain, and then as the temperature increased in the attrital bands as well. Marked increase in the hardness of the coal with increase of temperature applied accompanied the fissuring. Careful examination of all polished blocks revealed no vacuoles and the coal showed no indication of having become plastic. Since under natural conditions coke was produced at much lower temperatures in the Ruby and Peanut coals it may be concluded that both coals were of bituminous rank at the time of their vesiculation.

Importance of Thermal Metamorphism.

Although the Peanut and Ruby coal beds were locally subjected to temperatures sufficient to initiate coke formation it is possible that such a condition may have been incidental and not essential to anthracitization, the latter being inherently a pressure phenomenon at the zone of intrusion. On the other hand, heat and pressure may have been cooperative in their anthracitization effect. It is pertinent at this point to examine the facts bearing on this question.

Strata in the Mount Carbon field dip west at a rather uniform angle of 10 degrees. Such is true of those strata both above and beneath the laccolith as well as those on the eastern flanks. No compaction or distortion is noticeable in the shales, or fracturing in the sandstone, and no slipping appears to have occurred between beds of varying competancy. Only on the west flank where the coal is not exposed, but has been reported as an anthracite, has the intrusion produced local departures from the regional dip. On the eastern side of the mountain, anthracite is found where there is no noticeable departure from the regional structure. In contrast with the absence of local structural irregulari-

ties near the intrusion are strongly developed structural irregularities in the Star Mine several miles from Mount Carbon where the coal bed is faulted, slickensided, and is inclined at angles approaching 20 degrees. Yet, despite its attitude the coal remains of bituminous rank. The localization of anthracite in the Mount Carbon field in a position immediately adjacent to the periphery of the igneous mass is significant of its origin. Likewise, is the fact that the lowest rank coal of this same field (near Baldwin) does not occur at greater distances from the laccolith than other parts of the same bed which are of higher rank. The lower rank coal occurs where the beds have been only slightly tilted by the intrusion but not affected by heat. These relationships give basis to the probability that heat is essential for anthracitization. The amount of heat is necessarily uncertain but from observation of coal beds near the Anthracite Range or at Mount Carbon it is evident that the temperature must be high enough for considerable devolatilization, that is approximately 350° C.

Importance of Pressure in Coal Metamorphism.

Having estimated the probable temperatures accompanying the metamorphism of the coals in the Anthracite-Crested Butte region, the magnitude of the pressure involved in these changes is a matter of interest, since its importance is questioned. The pressure concepts involved are, (1) the additional weight of the laccolithic bodies, and (2) the pressure of intrusion.

Weight of Laccoliths.—In the Mount Carbon field, although the strata on the eastern flank of the laccolith show no evidence of having been subjected to strong pressure the anthracite bed below the intrusive is markedly slickensided along fractures and shows structures suggestive of cone-in-cone. In this situation the weight of the igneous rock is the only additional force not applied to the strata along the flanks of the intrusion where the coal bed does not display such features. The present thickness of the Mount Carbon laccolithic mass is 3,000 feet, and a thickness of 6,700–17,000 feet of sediments has been calculated as the minimum and maximum values, respectively of the sedimentary

load at the time of intrusion. Assuming 2.715 as the specific gravity of a quartz monzonite rock the laccolith imposes a weight of 3,000 pounds per square inch on the coal whereas the sediments (sp. gr. 2.4) add 7,000 to 17,000 pounds per square inch to the weight. The pressure on the anthracite due to the static load was therefore of the order of magnitude of 10,000 to 20,000 pounds per square inch or 700 to 1,400 atmospheres.

Pressure of Intrusion.—The pressure applied by the magma during intrusion may be assumed to be necessarily only sufficient to lift the weight of the superincumbent beds, but would have been hydrostatic and hence applied in all directions. It would appear, therefore, that a force at least twice that of the weight of the sediments and the igneous mass was applied to the anthracite forming a part of the floor sediments of the laccolith, and continuing as long as the laccolith was liquid. Thus the magnitude of the total pressure applied to the anthracite must have ranged from 1,400–2,800 atmospheres.

Importance of Shearing in Coal Metamorphism.

Comparison of the anthracite of the Richardson mine and that of the Ruby coal in Floresta Canyon, reveals considerable difference in physical structure due apparently to the effect of shearing action on the Ruby coal. In the Floresta field the anthracite bed is a single layer in a group of sediments forming the roof over the Anthracite Range laccolith, whereas the Peanut bed (Richardson mine) occupies a position in the sedimentary series lying beneath the Mount Carbon laccolith. The Anthracite Range intrusive resulted in the lifting of a huge mass of sediments as a block from a hinged fault along the north margin of the uplift. This type of uplift produced some movement of higher beds over lower at least between the Ruby coal bed and its overlying massive roof sandstone resulting in severe shearing within the relatively incompetent coal bed (Fig. 6). Slickensiding, and a rudimentary fracture cleavage are pronounced.

In contrast, the Peanut coal bed beneath Mount Carbon, although dipping about 10 degrees under the igneous mass, lacks

the very pronounced fracturing and high rank possessed by the Ruby anthracite. The chief differences in conditions affecting the two coals are (1) the shearing of the massive sandstone over the Ruby coal during the intrusion of the Anthracite Range laccolith, and (2) the difference in pressures applied to the coals as a result of the weight of the laccolith, sedimentary load, and pressure of intrusion. The Ruby anthracite was subjected only to the weight of sedimentary cover and probably did not bear the full hydrostatic pressure exerted by the intrusion since there are 300 feet of strata between the top of the intrusion and the Ruby coal. Theoretically, therefore, the Ruby coal appears to have been subjected to less pressure than the Peanut coal at the Richardson mine. Yet, the shearing produced by the movement of the roof sediments over the coal appears to have produced the anthracite of higher rank. The shearing, as may be clearly demonstrated in the field, was evidently a result of the intrusion and not a part of the regional deformation attending the formation of the Coal Creek syncline. Differential movement, which began while the coke was being formed, continued until carbonization ceased, for the solidified coke was fractured by the movement. The Ruby coal and coke alike show countless tiny fractures cemented by coaly matter but cut by later uncemented fractures. Such structural features seem to indicate that the coal even if not coked attained a semi-plastic state during heating. Apparently the formation of vesicles was prevented by the pressure that produced marked crushing of the less plastic portions of the coal bed. The fractures so produced were healed during a later period of cooling, and additional movement left uncemented breaks.

The importance in the development of anthracite of the forces that produced the shearing in the Anthracite Range is demonstrated when the effect of heat upon the Ruby and Peanut coals is investigated. Thermal metamorphism has been more intense on the flanks of the Anthracite Range than at the base of Mount Carbon, but the Richardson mine is only 50 feet below the laccolith whereas the Ruby coal lies 6 times that distance above the igneous mass. Therefore, despite the greater metamorphic halo

produced in the sediments of the Anthracite Range and the apparent tendency in this district for heat to be conducted through the roof sediments more readily than the floor, the writer considers the coal of the Richardson mine to have reached at least an equivalent temperature as that attained by the Peanut coal. The fact that the Ruby coal has reached a higher degree of metamorphism suggests the importance of some factor other than pure heating.

Relative Importance of Pressure and Heat in Anthracitization.

Although the strucural development of the Mount Wheatstone laccolith closely paralleled that of the Anthracite Range, deformation was not accompanied by shearing at the top, or within, the coal bed. Similar strata were involved and similar metamorphic effects were produced by the Mount Wheatstone and Anthracite Range intrusions. In the former, however, the extent of the metamorphic zone more closely resembles that observed adjacent to Mount Carbon. Comparison of the three occurrences reveals the relative importance of various factors influencing coal metamorphism in each body.

On Mount Wheatstone the Bulkley coal, at the southwestern limits of the Bulkley mine, lies approximately 500 feet above the intrusion, compared with 50 and 300 feet, respectively, for the coal beds of Mount Carbon and the Anthracite Range. Apparently a thickness of 500 feet of sediments was sufficient to dissipate the heat of intrusion to the extent that the resins in the Bulkley coal were neither melted nor volatilized. Hence it seems probable that the Bulkley coal never attained a temperature of 200° C., a temperature considerably lower than that experienced by the Ruby and Peanut coals.

The influence of pressure is discernible in certain parts of the Bulkley mine particularly in the southwestern limits where the coal dips 22 degrees away from the intrusion. The coal bed is slickensided and grooved on the cleat faces but there is no suggestion of the crushing characteristic of the anthracites of Floresta Canyon and the Slate River Valley. In the latter instances

tangential movement between beds seems to have been restricted to the horizon of the coal rather than uniformly distributed throughout the sedimentary series. In the Bulkley mine, however, the most prominent shearing effects shown in the coal bed are less prominent than those affecting the Peanut coal bed in the Richardson mine, where it has been demonstrated pressure seemed secondary in importance to heat in producing the effects observed. Theoretically the pressure exerted by the intrusion in deforming the coal bed at the Bulkley mine should be of the same order of magnitude as that attending the deformation of the Ruby coal bed. But, anthracitization of the Bulkley coal bed did not result since the intrusion was incapable of transferring the requisite temperature for such metamorphism through the additional thickness of sediments.

Importance of Folding in Metamorphism of the Slate River Valley Coals.

The Slate River Valley coal beds are included among strata only moderately folded and definitely unrelated to igneous activity. Anthracite is widespread among these coal beds, which are bituminous coals in the vicinity of Crested Butte and in the Mount Carbon field. Continuity of the beds makes gradation from rank to rank most noticeable in the case of the Bulkley and Peanut coal beds but it is generally characteristic of all coal beds. Within any particular locality all coal beds are essentially of the same rank, and, in general, the rank advances as the folding becomes more pronounced and as the distance from the igneous masses of Mounts Wheatstone, Axtell, and Crested Butte increases. Certain important exceptions exist respecting the direct relationship between folding and coal metamorphism particularly illustrated by the conditions in the Crested Butte and Pershing mines specially considered in the following paragraph.

The Crested Butte mine lies in the southern limb and the Pershing mine in the trough of the Coal Creek syncline. Within the Crested Butte mine the dip of the strata varies from 2 to 3 degrees to the northeast, whereas in the Pershing mine the strata are approximately horizontal. Coal of high volatile bituminous B rank

is produced from the Crested Butte mine and semi-anthracite from the Pershing mine despite similar thicknesses of sedimentary cover and conditions of folding. Nevertheless the effects of pressure are more marked in the coal of the Pershing mine and the mines farther north than in the Peanut coal of the Crested Butte mine. For example, coal in the Crested Butte mine has a strongly developed cleat resulting in blocky fragments and is broken by numerous faults of 5–20 feet displacement, whereas the semi-anthracite from the Pershing mine appears to have been thoroughly crushed. Slickensiding and deep grooving are prominent along the surfaces of millions of irregular fractures, many of which have been recemented by coaly material, and faulting is uncommon. Such differences in the behavior of coal under pressure suggest variations in the manner in which pressure is relieved. Thus, at the Crested Butte mine where adjustment during folding has been accomplished by faulting pressure upon the coal bed was released. Had faulting failed to develop adjustment would have been manifested in the compaction, devolatilization and hardening of the coal bed, evidenced by the development of many small breaks with polished, slickensided, and grooved faces, such as are characteristic of the semi-anthracite and anthracite of the Slate River Valley. Here again, as has been demonstrated in the Ruby coal bed (Floresta Canyon), the strains produced in the coal are the result of shear rather than the result of uniformly distributed pressure. Dependence upon shearing thus serves further to exemplify the importance of rotational stress in producing anthracite.

Importance of Heat in the Metamorphism of the Slate River Valley Coals.

Heat has had such undoubted importance in the development of anthracite at the Richardson mine and Floresta Canyon that the possibility of its attendance in the anthracitization of the coals of the Slate River Valley cannot be dismissed without consideration. In the latter district an appeal to the agency of heat must be made in order to account for certain facts which seem

anomalous under any theory of anthracitization which does not consider heat as a vital factor. For example, resins and waxes abundant in the Bulkley coal bed are only moderately common in the coal of the Crested Butte mine (Peanut bed) and completely absent in the Slate River Valley anthracites (Bulkley and Peanut beds). The absence of waxes and resins suggests either that they were altered to material not distinguishable from the coal substance or were volatilized. If the resins had been altered it is difficult to believe that alteration would obscure the fact that the altered material must possess a mode of occurrence similar to that of the resins and waxes. Absence of resinous bodies, therefore, is strongly indicative of their volatilization. The writer has also placed much emphasis on the crushed and fractured nature of the anthracites as distinct from the bituminous coals. But, many of the fractures are cemented by coaly material which must have been plastic in order to seal such openings. Apparently the cementation occurred at the time of fracturing and if so it becomes difficult to account for the behavior of the coal as both a brittle and a plastic substance simultaneously. But, if friction along each of the millions of small fractures was sufficient to raise the temperature of the coal along the surface of the break sufficiently to produce plasticity, cementation must follow upon cooling. Furthermore, since the frictional heat developed is dissipated throughout the entire coal bed it should be possible to raise the temperature of the entire stratum to that required for anthracitization, providing the fractures are sufficiently closely spaced to furnish the necessary heat. Because such an hypothesis appears to account for all the known facts related to anthracitization in the district, the thesis of multiple fracturing of the coal, by which sufficient heat is generated to begin anthracitization, is therefore the preferred explanation for the origin of the Slate River Valley coals.

CONCLUSIONS.

The outstanding problem of the coal beds of the Anthracite-Crested Butte quadrangles relates to the anthracitization of the

beds in the Slate River Valley. One solution to the problem has been advanced based on the assumption that the same factors effective in anthracitization of coal beds in other parts of the district were operative in the Slate River Valley. Evidence has been presented that both temperatures of 300–350° C. and pressures of the order of magnitude of 1,400–2,800 atmospheres are essential for anthracitization, for even in areas near intrusive bodies, neither agency is capable of producing anthracite without the other. In the district under consideration the similarity of the ultimate products in the areas adjacent to, and those remote from, intrusive bodies is such that the processes producing anthracite must have been closely parallel. To meet the apparently essential requirement for a temperature not less than 300–350° C. in the Slate River Valley anthracite area reliance is placed on the probability of development of frictional heat along fracture planes formed by countless small scale movements in the coal bed. When the coal bed is faulted in adjacent parts of the same general area (Slate River Valley) stress is dissipated thereby and strains concentrated in the coal bed may be incapable of raising the temperature of the coal bed sufficiently to alter it to anthracite.

NORTHWESTERN UNIVERSITY,
EVANSTON, ILL.,
March 1, 1939.

SIGNIFICANCE OF BORNITE–CHALCOCITE MICROTEXTURES.*

G. M. SCHWARTZ.

ABSTRACT.

The difficulty of working out accepted interpretations of the microtextures of ores has proven to be very great. A consideration of the large number of microtextures that have been described for a single pair of minerals, bornite, and chalcocite serves to indicate the reason for some of the difficulty. A list of bornite-chalcocite microtextures is given and each is briefly described and illustrated. A review of the possible significance of each is given.

INTRODUCTION.

THE intensive study of the microstructures and microtextures of polished surfaces of ores has now been carried on for twenty-five years. During this time a large amount of descriptive matter has accumulated. To many workers, especially the teacher, the interpretation and correlation of this mass of data is nearly hopeless. Attempts have been made to bring some order out of certain phases of the problem, and the work of the subcommittee on criteria of paragenesis of ore minerals appointed by the National Research Council [1] is a good example. Study of recent papers, however, shows much disagreement and variation in interpretation.

At first thought it seems that this chaotic condition is unnecessary and that the data should have been organized into a more usable form. Many difficulties appear, and the problem is not at all simple. The complexity is brought out forcibly each time a student examines a suite of copper ores from Butte or from

* Presented before the Society of Economic Geologists, New York Meeting, February 1939.

1 Bastin, E. S. and others: Criteria of age relations of minerals. ECON. GEOL., 26: 561–610, 1931.

several other well known districts. The relations of bornite and chalcocite alone furnish a good example. To make the problem concrete, it seemed desirable to bring together a summary of all of the observed relations between these two minerals with some comment on their interpretation and significance. It should be appreciated that the described relations are between only two of the approximately 100 common ore minerals. There are in addition about 100 less common or rare ore minerals.

ACKNOWLEDGMENTS.

The literature of the study of polished surfaces of ores has of necessity been drawn on freely and credit by footnote references has been given for all examples used. No attempt has been made to cite complete references on each of the textures. To do so would involve repeated references to practically every paper in which the minerals bornite and chalcocite are mentioned. An attempt has been made to list all distinct types of microtextures involving the two minerals, but to avoid minute subdivisions. It is believed that the ideas of the various authors have not been misconstrued in this grouping. If additional textures have been observed the writer would appreciate a reference to them or a description.

TABULATION OF MICROTEXTURES OF BORNITE AND CHALCOCITE.

1. Replacement along fractures and veinlets. Mesh patterns and "ice cake" texture.
   (*a*) Bornite replaced by chalcocite.
   (*b*) Chalcocite replaced by bornite.
2. Replacement controlled by cleavage.
   (*a*) Bornite replaced along cleavage by chalcocite.
   (*b*) Chalcocite replaced along cleavage by bornite.
3. Rim Pattern. Replacement along boundaries.
4. Reticulate Texture.
5. Graphic and subgraphic textures. Pseudo-eutectic or myrmekitic texture.
6. Pseudomorph textures.
   (*a*) Bornite cleavage preserved in chalcocite.
   (*b*) Bornite pseudomorphous after chalcocite crystals.
7. Lamellar, lattice, grating, Widmannstätten, bladed intergrowths.
8. Triangular (octahedral) pseudo-eutectic or eutectoid texture.

9. Spindle-shaped inclusions—Ex-solution texture.
   (*a*) Bornite inclusions in chalcocite.
   (*b*) Chalcocite inclusions in bornite.
10. Mutual boundaries.
11. Concentric textures.
12. Shred-like inclusions.
13. Inclusions along zones.

SUMMARY OF DATA ON MICROTEXTURES.

For each texture the following points are covered: (1) The various terms used for the same or similar textures with reference to some of the more important investigations and occurrences. (2) The textures are illustrated and briefly described. (3) The interpretation of the origin of the texture is given.

1. *Replacement along Fractures and Veinlets. Mesh Pattern. "Ice Cake" Texture.*

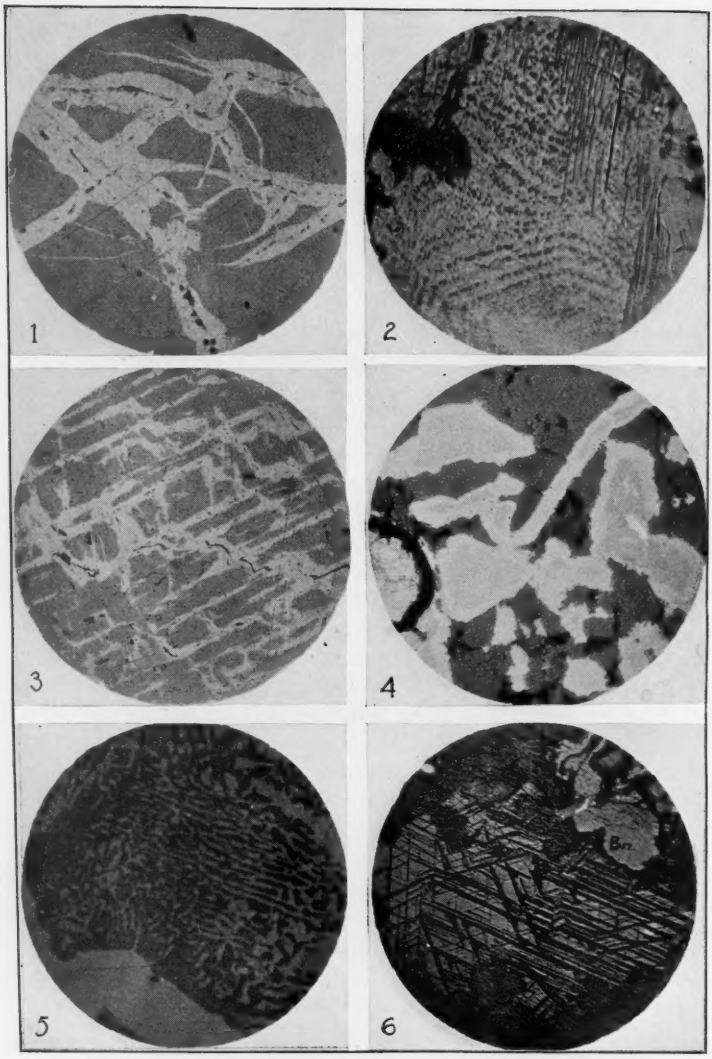
No doubt the most common relation between bornite and chalcocite is the replacement of bornite along fractures and veinlets by either hypogene or supergene chalcocite. This is a normal process of enrichment. The texture is shown by Fig. 1 and has been described in most papers on copper ores.

Less common but by no means rare is the replacement of chalcocite by bornite along fractures or other openings. This is sometimes referred to as reverse enrichment and is no doubt a result of local concentration of iron in solutions permeating the ores. It probably seldom takes place on a large scale but is an incident to other more pervasive processes. It is illustrated in Fig. 2 where it is associated with a more abundant pattern.

The term "mesh pattern" was used by Bateman[2] for veinlets of chalcocite criss-crossing areas of bornite forming a mesh, the threads and knots of which represent chalcocite. It is typical of supergene replacement.

Continuation of the process of replacement along fractures results in rounded or corroded fragments of the host mineral isolated in the guest mineral, the so-called "ice cake" texture.

[2] Bateman, A. M.: The ores of the Northern Rhodesian copper belt. ECON. GEOL., 25: 401, 1930.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The textures noted under this heading are commonly a result of replacement rather than simple fracture filling. There is no "a priori" reason why this replacement should not occur during either hypogene or supergene processes, but it is especially characteristic of supergene processes. This may be due in part to greater abundance of fractures in a supergene environment and also to the fact that cold, downward percolating solutions naturally seek out easy paths of progress.

2. *Replacement Controlled by Cleavage.*

Neither bornite nor chalcocite, as a rule, show well developed cleavage in hand specimen, but some can be seen microscopically on many polished grains, particularly on etching. This poorly developed cleavage serves to guide replacement in some ores as shown by Fig. 3. McLaughlin [3] has also shown a good example related to gangue veinlets. (Fig. 13.)

The writer does not recall having seen bornite replacing chalcocite along cleavage, but Overbeck [4] has suggested a possible example from the Liberty Mine in Maryland. He says regarding his Fig. 15, "An etched section of this piece shows that fingers

[3] McLaughlin, D. H.: Ore deposition and enrichment at the Evergreen Mine, Gilpin County, Colorado. ECON. GEOL., 14: Fig. 0, Plate 22, 1919.

[4] Overbeck, R. M.: A metallographic study of the copper ores of Maryland. ECON. GEOL., 11: 151–178, 1916.

FIG. 1. Replacement of bornite by chalcocite following cracks. Old Dominion Mine. Globe, Ariz. × 65.

FIG. 2. Bornite inclusions in chalcocite arranged along zones. Chalcocite also replaced by later bornite along a crack. Butte, Mont. × 230.

FIG. 3. Bornite replaced along a fracture and cleavage by chalcocite. Butte, Mont. × 90.

FIG. 4. Rim pattern. Chalcocite (white) surrounding bornite (light gray). Dark gray is gangue. Junction Mine, Bisbee, Ariz. × 100.

FIG. 5. Pseudo-eutectic texture of bornite and chalcocite. Butte, Mont. × 275.

FIG. 6. Chalcocite with central part showing isometric etch cleavage pseudomorphous after bornite. Bornite (Bn) remains in upper right hand part. Butte, Mont. × 80.

of bornite are parallel to the cleavage lines in the chalcocite crystal, a fact which suggests that the bornite is younger than the chalcocite, or at least contemporaneous with it."

The interpretation of these textures is essentially the same as that given above for fractures.

Many of the descriptions of lattice patterns refer to them as resulting from replacement related to cleavage. Surfaces such as that observed on a specimen of Butte ore (Fig. 8) give ample basis for this suggestion on first examination.

The explanation of chalcocite-bornite intergrowths as a result of replacement of bornite by chalcocite along cleavages has been a favored one throughout the microscopic study of ores. Papers by Segall, Ray, Tolman, and Jackson are good examples. Most of the illustrations are, however, susceptible to another interpretation that will be referred to below in the discussion of lattice textures.

A particularly good illustration of replacement with the bornite cleavage evidently controlling so that there can be no question is shown by Bateman.[5] Bornite is replaced at the contact with limonite by chalcocite with the development of an excellent rim pattern. Higher magnification of the rim shows an intimate crystallographic control of the distribution of chalcocite in bornite. The fact that the associated mineral is limonite, leaves little doubt that the replacement is supergene.

3. *Rim Pattern. Replacement along Boundaries.*

Next to fractures and cleavage, mineral boundaries are the most favored places for replacement, many with the consequent development of the so-called rim structure or texture (Fig. 4). The contacts may be between grains of the same mineral or between the replaced mineral and other ore minerals or gangue minerals. This has been noted by many investigators. Graton and Murdoch[6] described and figured the narrow zones of chalcocite

[5] Bateman, A. M.: The ores of the Northern Rhodesian copper belt. ECON. GEOL., 25: Fig. 15 A and B, 1930.

[6] Graton, L. C. and Murdoch, J.: The sulphide ores of copper. A. I. M. E. Trans., 45: 26–81, 1913.

around the boundaries of bornite areas. Bateman [7] used the term "rim pattern" which seems an apt, concise term to use in referring to this texture, thus obviating a longer description. Rim structure has also been used,[8] but rim texture would seem preferable if the term pattern is not used.

Rim patterns have been generally accepted as resulting from replacement, generally supergene. Jackson says that there is little doubt that this is the case at N'Changa where nine out of ten specimens containing chalcocite show this pattern.

In the interpretation of this texture, it should be recognized that although the texture is undoubtedly common in supergene ores, there is no compelling reason why it may not be formed by hypogene processes, especially in the later phases of activity. It may be permissible, therefore, to say that it is suggestive of supergene activity, but not proof of it.

4. *Reticulate Texture.*

Whitehead [9] used this term referring to triangularly reticulate intergrowths illustrated by Graton and Murdoch, Ray, and Segall. Several textures illustrated by these authors, however, seem to correspond to the triangular, octahedral or lamellar intergrowths described below. In Whitehead's figure 12, however, a reticulate intergrowth of chalcocite in bornite (Fig. 15), from Bristol, Connecticut, is illustrated in which the cleavage is only followed in a rough manner forming a crude rectangularly reticulate texture which is interpreted as a replacement. The texture is a characteristic type, which it seems best to classify separate from cleavage patterns noted above, inasmuch as Whitehead suggests that the chalcocite in this example followed its own crystallographic directions rather than that of the bornite. It therefore is not replacement along cleavage.

[7] Bateman, A. M.: Primary chalcocite, Bristol Copper Mine, Connecticut. Econ. Geol., 18: 122–166, 1923.

[8] Jackson, G. C. A.: The ores of the N'Changa Mine and extensions, Northern Rhodesia. Econ. Geol., 27: 247–280, 1932.

[9] Whitehead, W. L.: The paragenesis of certain sulphide intergrowths. Econ. Geol., 11: 1–13, 1916.

Jackson[10] also has illustrated minute reticulating veinlets of chalcocite in areas of bornite in a graphic intergrowth with chalcocite.

5. *Graphic and Subgraphic Textures. Pseudo-eutectic or Myrmekitic Textures.*

No texture has received so much discussion nor had so many terms suggested to designate it as the so-called graphic intergrowth or texture (Fig. 5). A complete discussion of this subject is unnecessary as it was reviewed in detail in 1931.[11]

In so far as chalcocite and bornite are concerned Laney[12] seems to have been the first to describe the texture which he referred to as a crystallographic intergrowth. Slightly later Graton and Murdoch[13] described these textures and used the term graphic intergrowth which has since been widely used for this type of texture in ores. The term has long been in use to designate a somewhat similar texture of quartz and feldspar. Lindgren[14] suggested the term pseudo-eutectic for these textures, which often closely resemble some true eutectic textures in metals.[15] Schneiderhöhn and Ramdohr[16] prefer the term myrmekitische verwachsungen (myrmekitic intergrowth) which Geijer[17] had previously adopted from Sederholm who used it for similar textures in rocks. Whitehead[18] has aptly described as follows the

[10] Jackson, G. C. A.: The ores of the N'Changa Mine and extensions, Northern Rhodesia. ECON. GEOL., *27*: 247–280, 1932.

[11] Schwartz, G. M.: Textures due to unmixing of solid solutions. ECON. GEOL., *26*: 739–763, 1931.

[12] Laney, F. B.: The relation of bornite and chalcocite in the copper ores of the Virgilinia District of North Carolina and Virginia. U. S. Nat. Mus. Proc., *40*: 513–524, 1911.

[13] Graton, L. C. and Murdoch, J.: Op. cit., p. 45.

[14] Lindgren, W.: Pseudo-eutectic textures. ECON. GEOL., *25*: 1–13, 1930.

[15] See for example, Green, C. H.: Eutectic patterns in metallic alloys. A. I. M. E. Trans., *71*: 651–665, 1925.

[16] Schneiderhöhn, H. and Ramdohr, P.: Lehrbuch der Erzmikroskopie, Berlin, 1931.

[17] Geijer, P.: Some Swedish occurrences of bornite and chalcocite. Sveriges Geologiska, Undersökning Arsbok 17, No. 2, 1923.

[18] Whitehead, W. L.: The paragenesis of certain sulphide intergrowths. ECON. GEOL., *11*: 1–14, 1916.

typical graphic intergrowth of chalcocite and bornite in ores from Bristol, Connecticut: "They are composed of twisting tongues of the sulphides with sharp smooth contact. The embayments and tongues turn sharply to form hooks and often join together to make an intricate network. The characteristic intergrowth contains the curved, elongate bodies of bornite and chalcocite in approximately equal width, but they often widen and narrow and may terminate in sharp, sword-like points. The intergrowths are generally notable for a graceful irregularity and an entire lack of any significant orientation of their component bodies."

Sub-graphic texture (Fig. 14) has been used to refer to poorly developed textures more or less resembling a typical graphic intergrowth (Fig. 5). Among those who have illustrated the texture for bornite and chalcocite are Graton and Murdoch, Bateman, and Short and Ettlinger.

So much controversy has arisen regarding the possible origin and interpretation of graphic texture that the texture itself cannot be used with confidence as a criterion for any particular origin. It seems probable that graphic textures may originate in more than one way. It is now generally accepted that the eutectic explanation is untenable. Investigations published in the past ten years seem about equally divided between the theory of origin by replacement or by contemporaneous deposition.

6. *Pseudomorph Textures.*

That bornite has commonly been replaced by chalcocite with the preservation of the cleavage of the bornite was recognized by Graton and Murdoch [19] and was discussed at length by Tolman.[20] Difficulty arises because of the possibility of confusion of pseudomorphous cleavage in chalcocite with the true octahedral cleavage of isometric chalcocite. It is probably necessary to use other criteria than the etch cleavage to determine the origin. Fig. 6 is an example of inherited cleavage in chalcocite from Butte. The

[19] Op. cit.

[20] Tolman, C. F., Jr.: Observations on certain types of chalcocite and their characteristic etch patterns. A. I. M. E. Trans., 54: 402–439, 1916.

shape of the area showing the etch cleavage as compared with adjacent areas of bornite suggests that the cleavage was inherited from replaced bornite. It is thus the shape of the area of isometric etch-cleavage rather than the cleavage itself that leads to the conclusion.

Only one example of bornite pseudomorphous after chalcocite was noted in the literature. This was described by Touwaide [21] from the Boleo copper deposit where partial and complete replacements of chalcocite crystals by bornite were described.

7. *Lamellar, Lattice, Grating, Widmannstätten and Bladed, Intergrowths.*

The lamellar intergrowth of lath-shaped chalcocite with interstitial bornite is one of the most common types of micro-texture found in bornite-chalcocite ore (Fig. 7). It has been described and illustrated in many papers of which those by Ray,[22] Locke, Hall, and Short,[23] Schwartz,[24] Schneiderhöhn and Ramdohr,[25] and Bateman [26] furnish good examples. The terms lamellar, lattice, bladed grating, Widemanstätten have been used to designate these intergrowths as textures, and there has been much debate regarding their origin and significance.

It has been shown experimentally that it is possible to produce these textures by unmixing of a solid solution. It is also clear that very similar, and possibly in some cases indistinguishable, textures may form by replacement. This emphasizes very forcibly the problem stated in the introduction. Not only do chalcocite and bornite occur with a great variety of textural re-

[21] Touwaide, M. E.: Origin of the Boleo Copper deposit, Lower California, Mexico. ECON. GEOL., 25: 113–144, 1930.

[22] Ray, J. C.: The origin and occurrence of certain crystallographic intergrowths. ECON. GEOL., 11: 179–185, 1916.

[23] Locke, A., Hall, D. A., and Short, M. N.: Role of secondary enrichment in genesis of Butte chalcocite. A. I. M. E. Trans., 70: 933–962, 1924.

[24] Schwartz, G. M.: Experiments bearing on bornite-chalcocite intergrowths. ECON. GEOL., 23: 381–397, 1928.

[25] Op. cit.

[26] Bateman, A. M.: The ores of the Northern Rhodesian copper belt. ECON. GEOL., 25: 365–418, 1930.

lations, but it is probable that some textures form in more than one way, thus adding greatly to the difficulty of interpretation.

8. *Triangular (Octahedral) Pseudo-eutectic, Eutectoid Texture.*

This type of texture is rare and was observed in heat treated specimens before it was found in a natural specimen [27] from the Mufulira Mine, Northern Rhodesia (Fig. 9).

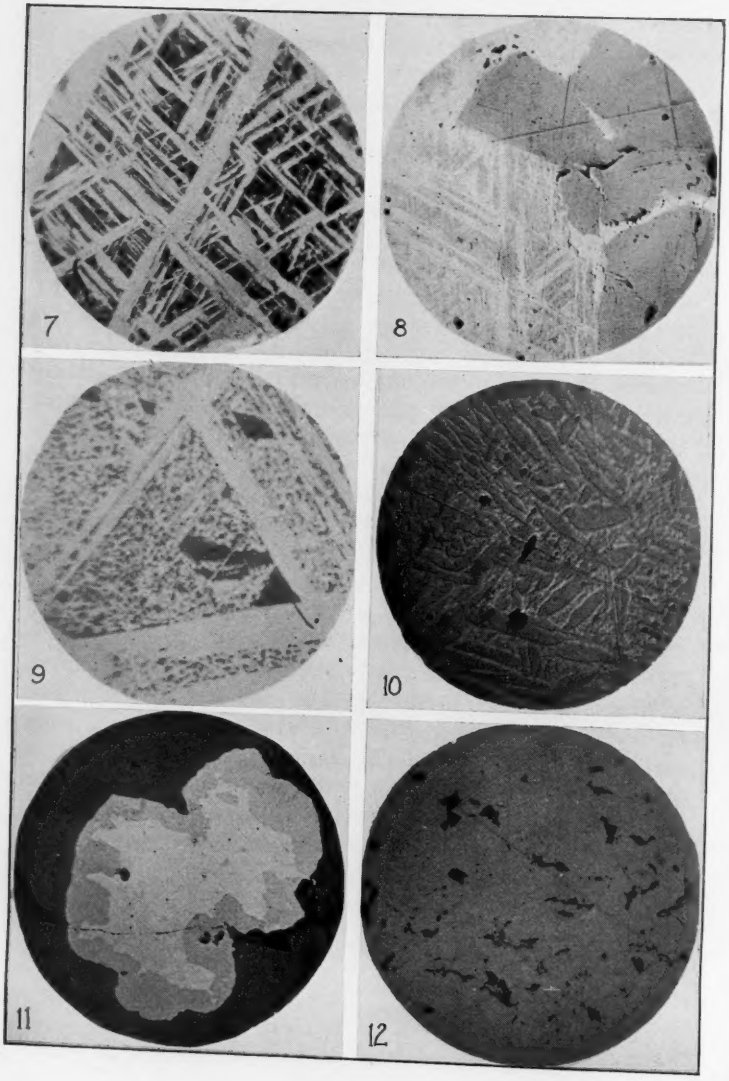
It has been conclusively shown that the texture may result from the breakdown of a solid solution, but whether or not it is a result of eutectoid conditions is a matter of inference. The writer has suggested that it is, but this has been questioned. The texture consists essentially of a series of laths of chalcocite forming triangles as viewed in polished section; presumably the laths are oriented along octahedral planes of the original solid solution. The matrix to the laths is a very intimate intergrowth of bornite and chalcocite (Fig. 9) somewhat like the pseudo-eutectic (graphic) texture described above.

The texture of the artificial sample probably developed somewhat as follows: [28] The original crystallization was as a solid solution of bornite and chalcocite. As cooling proceeded, chalcocite was present in excess and part ex-solved from the solid solution and formed along the octahedral planes of the solid solution crystals, which were presumably isometric. As cooling and exsolution proceeded further the eutectoid point was reached, that is, the composition and temperature at which the remaining solid solution unmixed at constant temperature to form the intimate intergrowth of the matrix.

It is therefore permissible to refer to the artificial texture as a probable eutectoid texture. For natural textures that are very similar (Fig. 9) but may have a different origin, no good term has been suggested. It is very difficult to get a concise term

[27] Schwartz, G. M.: Experiments bearing on bornite-chalcocite intergrowths. Econ. Geol., 23: 381–397, 1928. Fig. 10. A new natural intergrowth of bornite and chalcocite. Econ. Geol., 24: 443–444, 1929.

[28] The writer is indebted to Professor Ralph Dowdell of the Department of Metallography for a statement of a metallographer's interpretation of this texture and its development.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that will accurately designate such a complicated texture whatever its origin.

The term pseudo-eutectic or pseudo-eutectoid texture would not be proper because there are reasons for believing it is a true eutectoid texture.

The texture indicates a contemporaneous origin of the chalcocite and bornite by hypogene processes.

9. *Spindle-shaped Inclusions. Ex-solution Texture.*

Spindle-shaped inclusions of bornite in chalcocite (Fig. 10) have been described from Susie Island, Lake Superior, and have also been reproduced synthetically.[29]

The experiments prove that this texture may be formed by unmixing of a solid solution of bornite in chalcocite. This does not, however, preclude the possibility of their having formed in other ways in nature, but in the absence of evidence to the contrary, it is probable that they were formed by unmixing.

Probably to be classified with this ex-solution texture is the octahedral intergrowth described by Bateman[30] from specimens

[29] Schwartz, G. M.: Copper veins on Susie Island, Lake Superior. ECON. GEOL., 23: 762–774, 1928. Experiments bearing on bornite-chalcocite intergrowths. ECON. GEOL., 23: 381–397, 1928.

[30] Op. cit., p. 396.

FIG. 7. Lamellar chalcocite and bornite. An ex-solution texture. Butte, Mont. ×730.

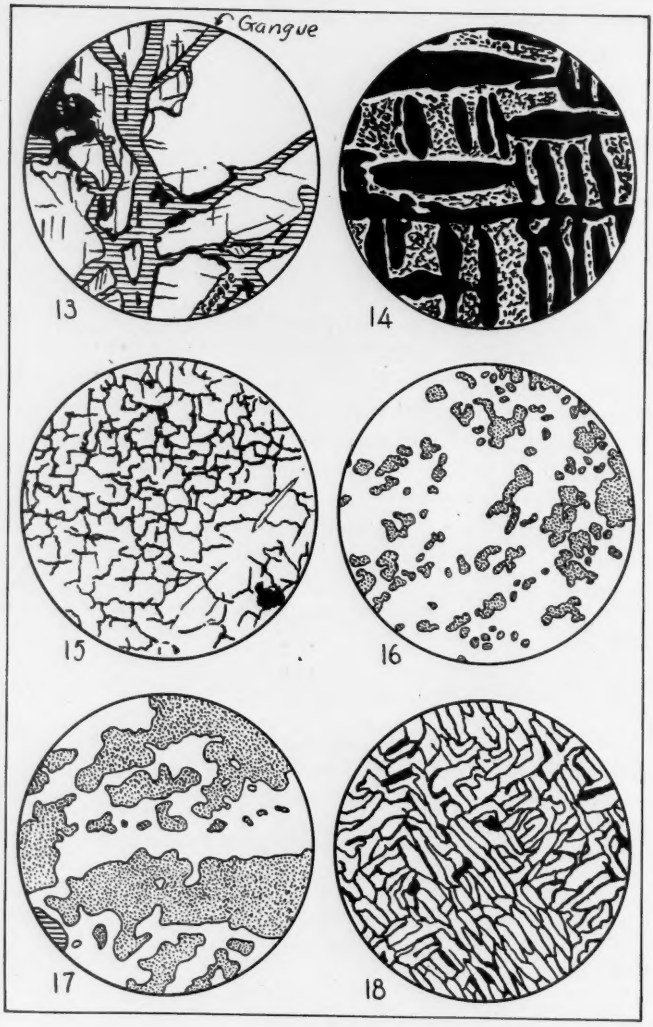
FIG. 8. Lamellar chalcocite intergrown with bornite. The intergrowth appears to replace bornite. The texture has been described as a replacement along the cleavage of bornite but is more likely a result of ex-solution. Butte, Mont. ×110.

FIG. 9. Blades of chalcocite with a matrix of a fine-grained mixture of bornite and chalcocite. This texture corresponds to that obtained by ex-solution at temperatures above the eutectoid point and at the eutectoid point. Mufulira Mine, Northern Rhodesia. ×630.

FIG. 10. Spindles of bornite in chalcocite. An ex-solution texture. Susie Island, Lake Superior. ×730.

FIG. 11. Concentric texture of chalcocite surrounded by bornite in calcite. Susie Island, Lake Superior. ×40.

FIG. 12. Shreds of bornite disseminated in chalcocite. Butte, Mont. ×230.


Gangue
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of Northern Rhodesian copper ores. He says, "these are octahedral partings in chalcocite, observable only under high magnifications with polarized light, along which are oriented small spindles of bornite." Van Aubel [31] and later Schneiderhöhn and Ramdohr [32] describe and illustrate chalcocite spindles in bornite from Katanga (Fig. 18).

Investigators who have described this texture have all considered it a result of ex-solution, and consequently also of hypogene origin.

10. *Mutual Boundaries.*

This texture has been described repeatedly for many minerals but is not particularly common in bornite-chalcocite specimens. Nevertheless, examples have been described (Fig. 17) and debate as to its significance has arisen. It has been used as a criterion for contemporaneous deposition.[33] Newhouse [34] has argued that the texture is not a safe criterion of such origin—he found an

[31] Van Aubel, R.: Sur les minerais de cuivre de la Haute-Lufira (Katanga Congo belge). Bull. de la Soc. Francaise de Min., 51: 161–165, 1928.

[32] Schneiderböhn, H., and Ramdohr, P.: Lehrbuch der Ermikroskopie. Berlin 1931, figure 150.

[33] Locke, Hall, and Short: Op. cit., p. 23.

[34] Newhouse, W. H.: Laboratory Investigation of Ores. New York, 1928, p. 160.

Fig. 13. Chalcocite (black) replacing bornite (white) along gangue contacts and cleavage. Evergreen Mine, Colorado. ×35. After McLaughlin.

Fig. 14. Cigar-shaped areas of bornite with complex of bornite and chalcocite between. Magma Mine, Superior, Ariz. ×90. After Short and Ettlinger.

Fig. 15. Reticulate network of chalcocite (black) in bornite. Bristol, Conn. ×1500. After Whitehead.

Fig. 16. So-called sub-graphic texture of bornite (stippled) in chalcocite. Butte, Mont. ×45.

Fig. 17. Mutual boundaries of chalcocite and bornite (stippled). Magma Mine, Superior, Ariz. ×90. After Short and Ettlinger.

Fig. 18. Spindles of chalcite white in bornite (black). Ex-solution texture. Haute Lufira, Katanga. ×900. After Schneiderhöhn and Ramdohr.

artificially formed replacement of bornite by chalcocite with the development of mutual boundaries. Recently Donnay [35] has argued very strongly against accepting mutual boundaries as a criterion for the contemporaneous formation of bornite and chalcopyrite in the Engels deposit. Geijer [36] in an earlier paper had also opposed the idea that contemporaneous deposition is indicated by mutual boundaries.

Closely allied to mutual boundaries is what may be better called mutual relation. This includes not only mutual boundaries but also variation in the relative abundance of the lesser mineral that occurs in the dominant mineral with each occurring as inclusions in the other. Bateman [37] has shown excellent examples of this relation in the ores from Bristol, Connecticut.

11. *Concentric Textures.*

In certain ores, such as the oxidized copper ores and the nickel-cobalt-arsenic ores of the Cobalt type, presumably deposited as a colloid, varied types of concentric textures are abundant. Such ores seem characteristic of ores in calcite veins and many such concentric textures occur in calcite-copper sulphide veins on Susie Island, Lake Superior.[38] Among these is one with a core of chalcocite surrounded by bornite (Fig. 11).

Bastin [39] has recently termed forms found in the cobalt-silver ores "dendrites of concentric structure." His description is as follows and corresponds exactly to the form of the bornite-chalcocite occurrence in the calcite veins of Susie Island. "These are branching masses of metallic minerals in a matrix of carbonate, each branch showing a concentric arrangement of its

[35] Donnay, J. D. H.: Genesis of the Engels copper deposit. Congres International des Mines, 1931, pp. 99–111.

[36] Geijer, P.: Op. cit.

[37] Bateman, A. M.: Primary chalcocite, Bristol Copper Mine, Connecticut. Econ. Geol., 18: Figs. 27 and 28, 1923.

[38] Schwartz, G. M.: Copper veins on Susie Island, Lake Superior. Econ. Geol., 23: 762–774, 1928.

[39] Bastin, E. S.: The nickel-cobalt-native silver ore type. Econ. Geol., 34: 39, 1939.

components much as a twig shows rings of growth. Around the nucleus may be one band or in rare cases as many as five or six."

It should be added that in the case of Susie Island, generally one band of each mineral occurs, or less commonly the dendrites are either all bornite or all chalcocite. As noted by Bastin these textures have frequently been interpreted as formed by diffusion of the metallic components through a gel prior to the reorganization of the minerals into their present crystalline forms.

The example illustrated (Fig. 11) may possibly be a rim pattern, but chalcocite replaces bornite throughout the ore, so it is probable that this texture is not a result of replacement. Study of many specimens led to the suggestion that bornite and chalcocite are contemporaneous in these dendritic forms.

12. *Shred-like Inclusions.*

Many specimens from Butte and elsewhere show chalcocite literally filled with minute shreds of bornite (Fig. 12). The first impression from these shreds is that they are remnants, but their uniformity in size and distribution as well as peculiar shape lead to doubt that they are a result of replacement of bornite. At high magnifications they may rarely be observed to be associated with minute areas of graphic texture and of inclusions in zones. It seems possible that they formed with the chalcocite. If they resulted from unmixing of a solid solution, it seems that they would show a more regular pattern, as is characteristic of exsolution textures.[40] If the bornite formed contemporaneously with the chalcocite but did not form a solid solution, the conclusion is almost inevitable that they were formed at low temperatures,[41] but not necessarily supergene.

The writer places the shred-like inclusions among the textures of doubtful origin. Observed associations suggest that they may

[40] Schwartz, G. M.: Textures due to unmixing of solid solutions. ECON. GEOL., 26: 739–763, 1931.

[41] Schwartz, G. M.: Experiments bearing on bornite-chalcocite intergrowths. ECON. GEOL., 23: 381–397, 1928. Ray, J. C.: Synthetic replacement of ore minerals. ECON. GEOL., 25: 433–451, 1930.

have the same origin as graphic textures and of inclusions along zones.

13. *Inclusions in Zones.*

In some chalcocite ores inclusions of bornite are arranged in rude zones (Fig. 2). These have been observed by the writer in ores from Butte, and from Bisbee. Locke, Hall, and Short [42] show a somewhat similar texture, which they refer to as an imperfect graphic pattern. It is possible that there is a gradation from the graphic pattern to the inclusions along zones, but it has not been observed, although the two patterns occur together.

The origin of zoned inclusions is somewhat of a mystery. It may possibly be an unusual result of unmixing, but this is not a satisfactory explanation because one should expect to see it more frequently if it is a result of a process thought to be common in the formation of chalcocite-bornite ores. Replacement does not ordinarily result in such zones. Possibly nearly contemporaneous formation with diffusion might result in such a texture. Perhaps it is just as well to admit that it is not known why or how such a texture forms. Experimental evidence would be particularly significant in such a case.

DISCUSSION.

The list of textures given above has not taken into account differences in the microstructure of bornite and chalcocite except as these affected the mutual relation of the two minerals. Chalcocite has a variable etch cleavage which has been described particularly by Tolman [43] and by Stephens.[44] The complexity of the textures described above might be increased by taking into account the fact that the chalcocite may have isometric, orthorhombic, or metacolloidal etch patterns, as classified by Tolman.

[42] Locke, A., Hall, D. A., and Short, M. N.: Role of secondary enrichment in genesis of Butte chalcocite. A. I. M. E. Trans., 70: 933–962, 1924.

[43] Tolman, C. F., Jr.: Observations on certain types of chalcocite and their characteristic etch pattern. A. I. M. E. Trans., 54: 402–435, 1916.

[44] Stephens, M. N.: The identification of types of chalcocite by use of the carbon arc. Econ. Geol., 30: 604–629, 1935.

The list of textures described by no means exhausts the possibilities of classification or subdivision. Perhaps many workers will think of bornite-chalcocite relations that do not seem to fall clearly into any of the 13 classes listed. A good example is furnished by Fig. 14 adapted from a paper by Short and Ettlinger.[45] This consists of spindle-shaped areas of bornite in a complex intergrowth of bornite and chalcocite.

The problem of interpretation is not only complicated by similar textures forming in different ways but by the fact that more than one generation of each mineral may be present in a specimen or even within a single field of the microscope.

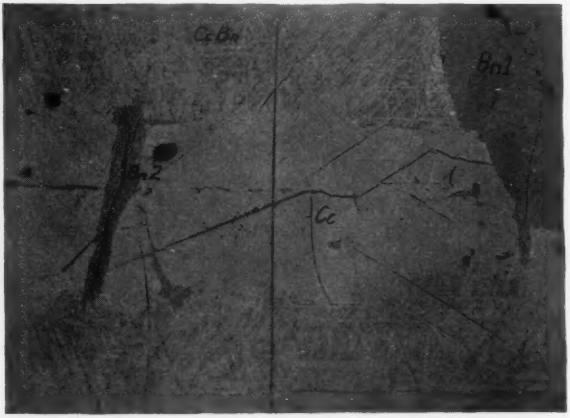

FIG. 19. Lattice texture of chalcocite and bornite. (Cc Bn) adjacent to an area of pure bornite (Bn1). Intergrowth cut by nearly pure chalcocite (Cc). Late bornite (Bn2) replaced chalcocite along crack. Butte, Mont. × 175.

Figure 19 is an example of these complications in a specimen of Butte ore. This figure is interpreted as follows, backed, of course, by a study of the entire specimen. At the upper right hand corner is a portion of an irregular area of bornite (Bn1).

[45] Short, M. N., and Ettlinger, I. A.: Ore deposition and enrichment at the Magma Mine, Superior, Arizona. A. I. M. E. Trans., 74: 174–222, 1926.

This insofar as can be determined is the earliest material. It is surrounded mainly by a lattic intergrowth of chalcocite and bornite (CcBn). This lattice intergrowth is similar to that interpreted by some investigators as a replacement of bornite controlled by cleavage and in more recent work as an ex-solution texture. The writer favors the latter for two reasons. The lattice texture has been produced in experiments by ex-solution and the contact of the intergrowth with the main mass of bornite is sharp. If chalcocite replaced bornite it should penetrate the main area of bornite (Bn1) along the cleavage. At the time of formation, before cooling, bornite (Bn1) was probably surrounded by a solid solution of bornite in chalcocite. The center of Fig. 19 is occupied by an elongate area of nearly pure chalcocite (Cc). This is part of one of several elongate areas that seem to be in the nature of veinlets cutting the earlier ex-solution texture. Whether this chalcocite formed before or after ex-solution does not seem clear.

Finally, a late generation of bornite (Bn2) has formed along a crack by replacing the later generation of chalcocite. This late bornite may well be supergene, but available evidence is not sufficient to make this at all conclusive. The usual criteria would indicate that all of the specimen except possibly the bornite along cracks is hypogene.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
March 3, 1939.

SHADES AND SCREENS FOR ISOMETRIC BLOCK DIAGRAMS.

RONALD L. IVES.

ABSTRACT.

Shading of isometric block diagrams, and the application of distinguishing patterns to stratigraphic units depicted in them, can be greatly simplified by the use of modern art aids such as Ben Day screens and toned papers. Costs of production and reproduction may be greatly reduced, and the quality of the finished figures increased, by the skilful use of these aids. Methods of effectively applying distinguishing patterns are described in this paper.

INTRODUCTION.

ISOMETRIC block diagrams produced by the methods recently outlined by Johnston and Nolan [1] are useful illustrative media, but, as commonly executed, lose a great part of their effectiveness because of unfortunate application of shadings and distinguishing patterns, with a resultant obscuration of lines bounding the various surfaces and indicating the structures.

Diagrams of this type, produced by the usual drafting methods, in which geometrical lines and distinguishing patterns are hand-drawn, and shadings applied by air-brushing, must be reproduced by the relatively expensive half-tone process, which tends to introduce disconcerting aberrant elements into the patterns, particularly on the darker surfaces.

Production of workmanlike isometric block diagrams has been limited, in the past, to institutions where skilled air-brush work is available. Hand-painted shadings are almost invariably unsatisfactory.

SHADING.

Two of the three cube faces usually represented in an isometric block diagram are normally shaded to minimize confusion be-

[1] Johnston W. D., Jr., and Nolan, T. B.: Isometric block diagrams in mining geology. ECON. GEOL., 32: 550–569, 1937.

tween the various planes. Designation of these faces, to clarify the discussion of shading to follow, is shown in Fig. 1. Here, the top cube face is designated by *A*, the left front face by *B*, the right front face by *C*, and the background by *X*. After the conventional shadings are applied, the cube of Fig. 1 resembles Fig. 2.

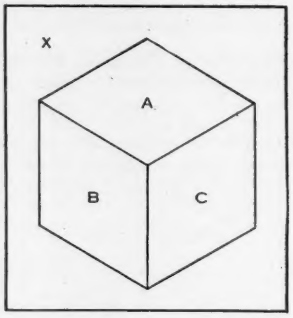

FIG. 1. Designation of surfaces.

Normally, the *A* face and the *X* surface receive no shading, the *B* face is darkened slightly, and the *C* face considerably. Eckel's *Block Diagram of May Day and Idaho Mines,*[2] is a good example of a block diagram conventionally shaded by the use of solid tones.

Solid Tone Shading Methods.

Several methods of applying shading tones without the use of the air brush are applicable. All of these are basically photographic, and all are quite simple in theory, although a few of them are quite laborious. Where solid tone shadings are used, the diagram must be reproduced by the half-tone process. Solid tone shadings resemble Fig. 2 quite closely.

Partial Exposure Method.—Shading of surfaces can be accomplished photographically by covering areas to be shaded, dur-

[2] Eckel, E. B.: Resurvey of geology and ore deposits of the La Plata mining district, Colorado. Colo. Sci. Soc. Proc., 13: p. 544, pl. 2, 1936. This figure is also reprinted in Johnston and Nolan's paper, op. cit., p. 556, pl. 4.

ing photographic copying, with black paper during a part of the exposure. When this method is used, the *A* face (and faces parallel to it) and the *X* surface are not covered during any part of the exposure; the *B* face (and faces parallel to it) is covered with black paper for a small fraction of the exposure time; and the *C* face (and faces parallel to it) is covered for a larger fraction of the exposure time. In general, when copying is done on "straight line" films, such as regular orthochromatic, the *B* surfaces should be covered for about 1/5 of the exposure time, and the *C* surfaces for about 2/5 of it. Some alteration of the tones pro-

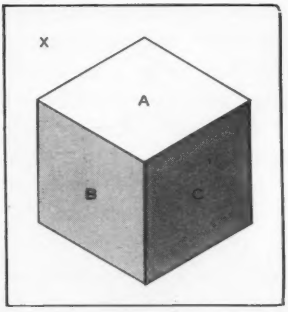

FIG. 2. Solid tone shading.

duced can be made by using harder or softer printing papers, by varying printing time, or by over or under development of the prints from the copy negative.

Reduction Method.—Shading of diagrams already copied can be done by chemical treatment of the copy negative. Areas needing no shading are carefully varnished, and the copy negative placed in a chemical reducer, such as Farmer's,[3] until the density is slightly reduced. This produces the light tone. The negative is now washed and dried, and the light-toned areas varnished. When the varnish is dry, the areas to receive the dark tone are

[3] A ferricyanide-hypo reducer. Mees, C. E. K.: Elementary Photographic Chemistry. Rochester, 1936, p. 78. Numerous alternative formulae are given in Wall, E. J.: Intensification and Reduction. Boston, many editions.

further reduced, and the negative washed and dried. After drying, the copy negative is practically identical with one produced by the partial exposure method.

Chromatic Shading.—When colored objects are photographed on films of the panchromatic variety, different colors are rendered in the print as different shades of gray. This film characteristic can be taken advantage of to shade isometric block diagrams. The *A* surfaces are left white, the *B* surfaces covered with cellophane or Ben Day color sheet,[4] which will produce a light gray in the print from the particular copy film used, and the *C* surfaces covered with a medium that will produce a darker gray in the print. Copying is now done in the usual manner, and the copy negative closely resembles that produced by the two shading methods already described. Fig. 2 was produced by this method, the *B* surfaces being covered by "solid orange" Ben Day, and the *C* surfaces by "solid red." Process panchromatic film and a high contrast developer, such as Eastman D–8, produce the desired contrast.

Linear Shading.

When a system of uniformly-spaced parallel dark lines on a light surface is viewed from a distance, the human eye-brain system interprets it as a solid gray. If the lines are closely spaced (55 or more lines to the inch), the surface on which they are ruled will appear a solid gray at normal reading distance. The darkness of the apparent gray increases *approximately* as the widths of the lines. Typical linear shading is shown in Fig. 3, where a parallel ruling gives the *B* surface a light tone, while a cross-ruling gives the *C* surface a darker tone. When the dark tone is produced by a cross-ruling of the same line width and spacing as the parallel ruling producing the light tone, the dark toned area will be somewhat less than twice as dark as the light toned area.[5]

[4] Made by Para-Tone Co., Inc., Chicago, Ill.

[5] In a cross-ruling, where the lines have a width W and a center-to-center spacing S, the ratio of black area to total area (per cent black), regardless of the angle of intersection of the rulings, approaches $[W(2S-W)]/S^2$ as the number of intersec-

Linear shading is useful in simple figures, and in those which are to be reproduced on coarse paper, such as newsprint. Several methods of applying linear shading, other than by hand-ruling, are practicable.

In isometric block diagrams, the lines used for shading should make angles with the vertical center line of the figure that are odd multiples of 45 degrees, so that "pattern fight" (Fig. 9) is minimized.[6]

Doubletone Shading.—Linear shading of isometric block diagrams can be neatly and quickly done by drawing the figures on

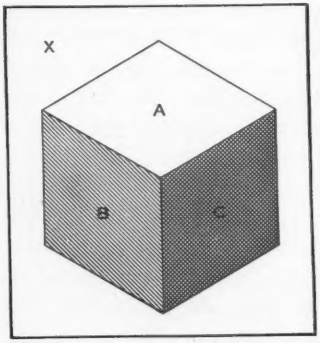

FIG. 3. Linear shading.

Doubletone paper.[7] This is a special drawing paper, into which two sets of rulings have been printed at right angles in nearly-invisible chemical ink. After the line work is finished, the tones are developed out chemically, one solution darkening a parallel

tions approaches infinity. In a parallel ruling, the ratio of dark to total area (per cent black) is W/S. Hence, where the same pattern is used to produce both light and dark shadings, with a single application on the light-toned areas, and two intersecting applications on the dark-toned areas, the ratio of the blacknesses of these areas approaches $(2S-W)/S$ as the number of intersections approaches infinity, and has this value, for all practical purposes, if more than about 100 intersections occur in a patterned area.

[6] Bull, A. J.: Photo. Jour. (London), 78: 130–132, 1938.

[7] Made by the Craftint Mfg. Co., Inc., Cleveland, Ohio.

ruling, the other darkening both sets of rulings. Doubletone paper is available in several different line widths and spacings. Liberal quantities of developing solutions are supplied by the manufacturers of this paper, as are detailed instructions, which must be followed *exactly* if good results are to be secured. Doubletone shading is substantially identical with that shown in Fig. 3. A complete simple block diagram shaded by the use of doubletone paper is shown in Fig. 6.

Shading With Linear Ben Day.—Linear shadings can be applied to block diagrams (or any other figures) by the use of linear Ben Day, an art aid consisting of a transparent base upon which various patterns are printed in opaque ink. This is placed over the areas to be shaded, fastened there, and the excess pattern trimmed away. Two general types of Ben Day are available:

A. "Top Sheet" Ben Day, composed of a sheet celluloid base on which the pattern is printed in removable opaque ink. This type of Ben Day is held in place with rubber cement, and excess pattern can be removed either by scraping or cutting.[8]

B. Self-adhesive Ben Day, composed of cellophane, on which the pattern is printed in opaque ink. Over the pattern a layer of waxlike adhesive is spread. This is placed over the area to be patterned, with the waxy side down, and rubbed firmly until it adheres. The excess pattern is cut away, after which the edges are rubbed firmly to make adhesion permanent.[9]

Either type of Ben Day will give satisfactory results. Dark tones are best produced by applying two layers of linear Ben Day with the rulings at right angles. Fig. 3 was shaded by the use of self-adhesive linear Ben Day.

Stipple Shading.

When an isometric block diagram is to be reproduced on high-quality paper, and maximum clarity is desired, stipple shading, closely resembling that produced in a half-tone reproduction of a solid-shaded figure, gives best results. This shading may be ap-

[8] Made by the Craftint Mfg. Co., Inc., Cleveland, Ohio.

[9] Made by the Para-Tone Co., Inc., Chicago, Ill.

plied in several ways, the finished product, in each case, closely resembling Fig. 4.

Stipple shading consists of dots symmetrically arranged. The relative darkness of the shading varies (almost) directly with the diameter of the dots. Thus, light and dark tones can be produced by using light and dark stipple Ben Day. In general, the easiest way of applying this shading is to cover the *B* and *C* faces with the lightest-toned stipple Ben Day (of either type) available, and then to make a second application of the same pattern over those areas to receive the dark tone (the *C* surfaces). In this manner, the relative darkness of the two surfaces can be

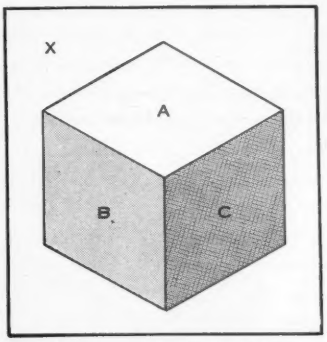

FIG. 4. Stipple shading.

varied within wide limits, an exact superimposition of the second pattern (dots in one pattern directly over those in the other) over the first giving the *B* and *C* surfaces the same tone, while if the dots of the second pattern fall over the spaces of the first, the dark tone will be twice as dark as the light tone. Any intermediate shading desired can be produced at will.

Careful orientation of the second pattern will be necessary to prevent "pattern fight" (Fig. 9), which, although largely illusory, is extremely disconcerting to the reader.

The labor of applying and trimming Ben Day can be reduced by drawing the figure on stipple-toned paper, developing out the

tone in the *B* and *C* areas, then applying Ben Day of the same pattern over the *C* areas. This is possible because stipple-toned paper [10] and " Top Sheet " Ben Day are manufactured in the same patterns and sizes. A complete simple isometric block diagram shaded by means of (self-adhesive) stipple Ben Day is shown in Fig. 7.

Shading of Special Faces.

On occasion, because of the complexity of the structure to be shown, or for other reasons, faces other than those parallel to the cube faces must be used in isometric block diagrams. Shading of these faces, necessary for meticulous correctness, can be determined by means of complicated formulae. The production of these exact shades is difficult, and in many instances, after the shades are applied, they so closely resemble those of the normal faces that confusion, rather than the increased clarity which is the sole reason for applying shadings, is the result.

It seems advisable, in view of this difficulty, to adopt a conventional treatment for special faces, rather than to attempt shadings. As special faces are drawn only when the desired features cannot be shown clearly by means of the ordinary faces, it seems reasonable to leave these special faces unshaded, and to apply a very light shading to the *A* face, if this is necessary to prevent confusion of surfaces. Such treatment is shown in Fig. 5, where the octahedral face, *O*, and the prismatic faces, *P*, and *Q*, are left unshaded, the *A* face lightly stippled, and the *B* and *C* faces normally shaded by means of linear Ben Day. This treatment of special faces brings them into prominence, and makes them the first part of the figure seen by the average reader.

DISTINGUISHING PATTERNS.

Lithologic units depicted in isometric block diagrams are normally patterned so that they may be distinguished, one from an-

[10] Marketed under the trade name " Singletone " by The Craftint Mfg. Co., Inc., Cleveland, Ohio. Several other varieties have appeared on the market from time to time.

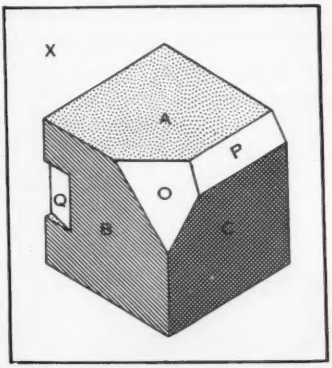

FIG. 5. Treatment of special faces.

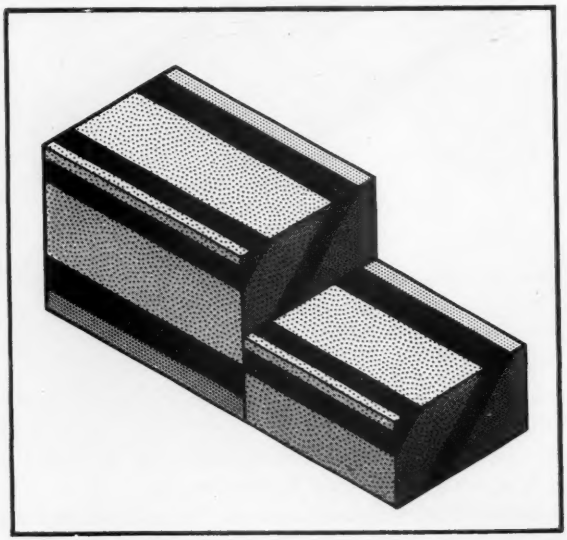

FIG. 6. Simple isometric block diagram shaded by means of Doubletone paper.

other. The choice of these distinguishing patterns, or "screens," is important, for if a stratum is improperly screened, structural lines will be obscured, the stratum confused with another, or offensive aberrant pattern elements ("pattern fight," Fig. 9) introduced.

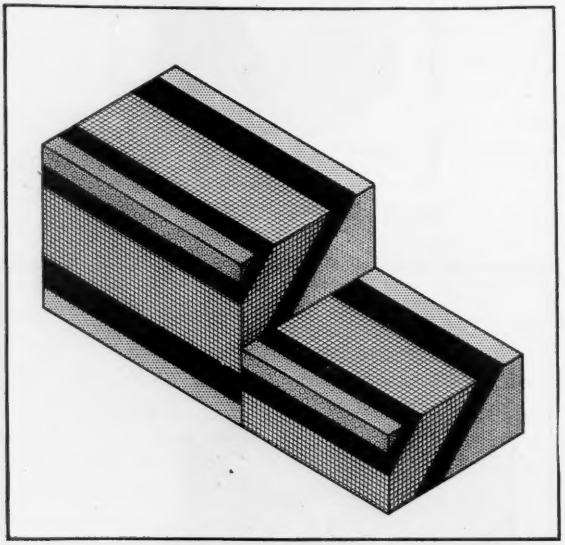

FIG. 7. Simple complete isometric block diagram shaded by means of stipple Ben Day.

Distinguishing patterns, or screens, to be effective, must have the following qualities:

1. Patterns must be easily distinguished, one from another, no matter how much the figure is reduced in size.

2. Distinguishing patterns must not "fight" with the shading patterns.

3. Patterns must not introduce "lead lines," which give the impression of a structure not actually present in the area depicted.

Pattern Types.

More than 100 Ben Day patterns are at present commercially available. About half of these are suitable for use in geologic illustration. The general types of patterns suitable for use in isometric block diagrams will be briefly described. Examples of these types are shown in Fig. 8.

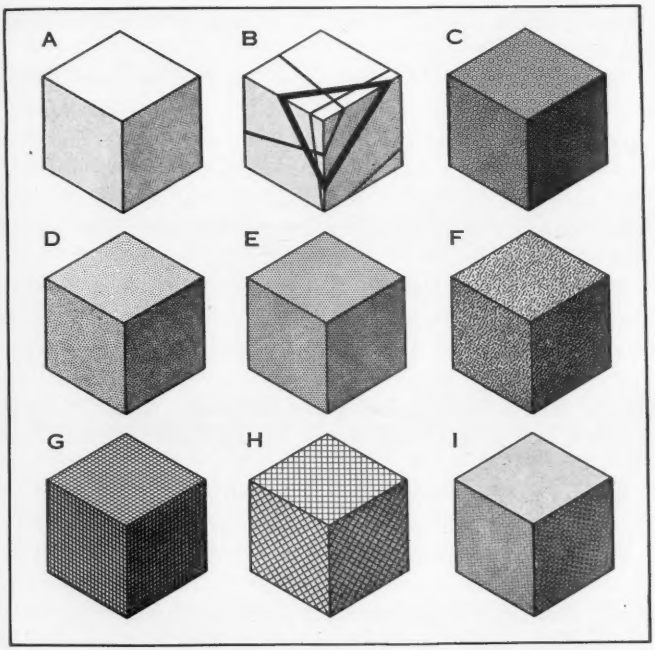

FIG. 8. Various distinguishing patterns.

Black and White.—Black shading, applied by inking in the area, is suitable for thin strata. Where possible, one stratum near the center of a diagram should be solid black to give an "index bed." Use of solid black will be noted in Figs. 6 and 7, in Fig.

8 *B*, and in Fig. 10 to depict "La Plata Limestone." Note how, in Fig. 10, this use of solid black increases the clarity of the figure. White is also useful to depict a stratum, as it, like black, provides an "index bed" easily traced throughout the figure. When white is used to depict a stratum, the regular shadings are used. In the case of solid black, the shadings are completely obscured. Use of white is shown in Fig. 8 *A*, and in Fig. 10 ("Middle La Plata Shale"). White is best used on a rather extensive bed. Where possible, one bed in each block diagram should be white, and another black.

Random Patterns.—Numerous random Ben Day patterns are available. These are divided into two general types—random stipples, shown in Fig. 8, *D* and used to depict "Upper La Plata Sandstone" in Fig. 10; and areal random patterns, shown in Fig. 8, *F* and used to depict "Mc Elmo Formation" in Fig. 10. After black and white, random patterns are most suitable for use in block diagrams.

Radial Patterns.—Radial patterns, with the elements arranged like the spokes of a wheel, are more or less nondirectional, and may be used to shade strata in block diagrams. These patterns, in general, tend to be quite dark, and hence should be used for beds of little importance in the area depicted. A radial pattern is shown in Fig. 8, *C*, and is used for the Cutler Formation in Fig. 10.

Equilateral Patterns.—Patterns in which the elements are placed at the apices of an equilateral triangle, such as that shown in Fig. 8, *E*, may be used in isometric block diagrams provided the "rows" of pattern elements are parallel to the sides of the surfaces. Any other arrangement introduces unwanted "lead lines." An equilateral stipple is used to depict the Dolores Formation in Fig. 10.

Linear Patterns.—Parallel rulings, so useful in plane drawings, are entirely useless in isometric block diagrams, as they introduce confusing "lead lines," suggesting stratification where none is present. Such confusion occurs in Eckel's *Block Diagram of May Day and Idaho Mines*, where a double ruling depicts the

"Mc Elmo Formation."[11] It will be noted, from reference to this figure, that the confusion, although unavoidable, has been minimized by skilful use of different line widths for structures and patterns. Cross-rulings may occasionally be used as distinguishing patterns, provided the area to be patterned is small, and also provided that the rulings bisect the angles between the coordinates of the figure. This treatment is shown in Fig. 8, *H*. By applying a parallel ruling twice to each surface, with the pattern lines in each case parallel to a coordinate, an isometric cross-ruling is produced. This is satisfactory for general use, and is shown in Fig. 8, *G*. The "Lower La Plata Sandstone" of Fig. 10 is patterned by use of an isometric cross-ruling, as is the middle stratum in Fig. 7.

Isometric cross-rulings are most simply produced by applying a linear Ben Day screen to the *A* and *B* surfaces, with the rulings parallel to their common coordinate; then applying the same pattern to the *B* and *C* surfaces, again with the rulings parallel to the coordinate common to both surfaces; and finally applying the pattern to the *C* and *A* surfaces, with the rulings parallel to the coordinate separating these faces. This method requires a minimum of trimming.

Unsuitable Patterns.—A few of the commercially-available Ben Day patterns are entirely unsuitable for use with isometric block diagrams. These, in general, are those patterns that are neither true random nor truly regular, and include the "hand made" rulings, "rustic" cross-rulings, and wavy line patterns so much used in art work. In addition to these, patterns more than 50 per cent black should be avoided whenever possible. Dark patterns tend to degenerate into unwanted solid black shades in the final reproduction, as a result of optical illusions, capillarity of the printing paper, and the "spread" of lines, which is unavoidable in even the most skilfully made engravings.

Avoidance of Pattern Confusion.

If two strata depicted in an isometric block diagram are easily confused, the effectiveness of the figure is considerably reduced.

[11] Eckel, Edwin B.: Op. cit.

When published diagrams, usually much smaller than the original figure, are viewed from a distance, the distinguishing patterns tend to degenerate into shades of gray, the shade depending on the relative area of the dark pattern elements, irrespective of their arrangement. Hence, two dissimilar patterns, such as an isometric cross-ruling and a random stipple, may be confused in a small published figure if the relative area of the black lines in the cross-ruling equals that of the dark dots in the stipple.

This trouble is eliminated by using patterns that have a different percentage of black in each. The probability of confusion may be determined before the patterns are applied by placing them close together and viewing them either through a reducing glass or from a distance. Patterns that look alike under these conditions will probably be confused in the finished figure.

Avoidance of "Pattern Fight."

"Pattern fight," the result of improper combination of patterns, occurs when elements of two patterns combine to produce a third, unwanted, pattern. A typical example of pattern fight is shown in Fig. 9, where a radial and a line pattern are combined. Elements of both these patterns, in combination, produce the diagonal dark bands, which, when the figure is viewed from a distance, are the predominant pattern.

Pattern fight occurs in isometric block diagrams when the shadings and distinguishing patterns are too nearly the same size, or when the angles between the trends of the elements in the two patterns are very acute.

Unpredictable pattern fight occurs in isometric block diagrams, after reproduction, when solid shadings are used. Here, the screen pattern, introduced to permit reproduction of the solid shades, conflicts with the distinguishing patterns. Some pattern fight will be noted in the darker parts of the *C* surfaces of Eckel's diagram.[11] In this instance, the trouble is solely caused by the method of reproduction, no "fight" being possible between the solid shading and the linear patterning of the original.

Photoengravers, struggling with the problem of superimposing three and four impressions in color photography, have determined that when the angles between the trends of the pattern elements are greatest, the pattern fight is least. This can be demonstrated mathematically. In isometric block diagrams, if the trends of the shading pattern elements, whether lines or rows of dots, are oriented to make angles of odd multiples of 45 degrees with the base line, while distinguishing patterns are oriented to make angles with the base that are multiples of 30 degrees, the angles between the trends of the pattern elements will be greatest, and the pattern fight due to angular effects least.

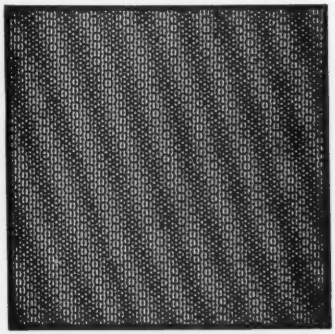

FIG. 9. "Pattern fight."

Angular pattern fight is completely avoidable only in rare instances, but it may be reduced considerably by careful orientation of shading and distinguishing patterns.

Pattern fight resulting from similarities in the sizes of the elements in the shading and distinguishing patterns is reducible only by using distinguishing patterns in which the elements are very much larger than those in the shading patterns. The result of using a screen of the same size for both shading and stratum identification is shown in Fig 8, *I*, where the same screen was applied three times—once over the whole figure, to identify the

stratum, twice over the *B* and *C* faces, to produce the light tone, and three times on the *C* face, to produce the dark tone. Pattern fight resulting from similarities of size also may be noted in Fig. 6, where the dots of the equilateral stipple coincide with the white spaces between some of the shading lines.

Size-caused pattern fight is rather hard to eliminate completely, as distinguishing patterns must have elements small enough to be recognizable in the smallest area patterned, and shading patterns must be large enough to permit reproduction. Some " trial and error " experimentation is necessary, in many instances, to determine just what distinguishing patterns may be used successfully with a given set of shading patterns. When linear or stipple shadings are used, however, the appearance of the published figure is exactly known before the diagram is sent to the engraver, and any pattern fight present in it is the fault of the draftsman, not of the engraver.

LETTERING.

Lettering of isometric block diagrams is always a problem, for no system of distortion " looks quite right," not even the most carefully worked out and mathematically correct systems in which the slant of the letters in each word is laboriously determined by the methods of descriptive geometry. To avoid this difficulty, and to minimize the labor of making these diagrams, it seems reasonable to conventionalize, and to insert each letter with its base parallel to the base of the figure. This convention permits the use of " pasteup " lettering—letters, printed on paper from regular type, are cut out and cemented into place where desired. This method of type insertion was used in Fig. 10, which is a copy of Eckel's diagram [11] shaded by the use of stipple Ben Day and patterned by application of random, radial, equilateral and linear Ben Day screens.

FIG. 10. Block diagram of May Day and Idaho Mines.
(After E. B. Eckel.)

SUMMARY.

After completion of the line work of an isometric block diagram by methods well known and adequately described,[12] the time necessary for shading and application of distinguishing patterns can be reduced from days to hours, and the quality of the finished figure improved, by the use of various art aids.

Use of the airbrush is unnecessary when shading is applied by any of the photographic shading methods.

Reproduction by relatively inexpensive line cuts, instead of by the more costly half-tone process, is made possible by the use of either linear or stipple shading. This also allows the draftsman to determine in advance, and before an expensive cut is made, the exact appearance of the published figure.

Annoying pattern troubles can be minimized by the proper selection and orientation of distinguishing and shading patterns.

Lettering is simplified by adoption of a conventional method of application.

ACKNOWLEDGMENTS.

Experiments with various art aids, from which the methods described in this paper were developed, were suggested by Dr. W. D. Johnston, Jr., of the U. S. Geological Survey, to whom the writer is indebted for many helpful discussions of the problems of diagram construction, and for a critical reading of this paper. The writer is grateful to Mr. Edwin B. Eckel, of the U. S. Geological Survey, who, knowing that it would be adversely criticised, generously gave permission for the use of his "Block Diagram of May Day and Idaho Mines" as a "trial horse."

BOULDER, COLO.,
March 9, 1939.

[12] Johnston, W. D., Jr., and Nolan, T. B.: Op. cit. Lobeck, A. K.: Block Diagrams. New York, 1924, pp. 119–147.

TELLURIDE–TUNGSTEN MINERALIZATION OF THE MAGNOLIA MINING DISTRICT, COLORADO.

ALBERT S. WILKERSON.

ABSTRACT.

Two systems of fissures in the Magnolia Mining district of Boulder County, Colorado are occupied by ore deposits—a northwest system is mineralized with various tellurides, and a northeast system contains tungsten. The relation between these mineralized fissures with barren regional faults is discussed.

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INTRODUCTION AND ACKNOWLEDGMENTS.

FIELD work in the Magnolia mining district was done by the writer during the summers of 1936 and 1937. Microscopic examination of thin sections and polished sections was carried on during the winter of 1937–38 at the University of Michigan. The writer is greatly indebted to T. S. Lovering for invaluable aid in the preparation of this paper.

LOCATION AND HISTORY.

The Magnolia mining district lies four miles southwest of Boulder, Colorado and is a part of the maturely dissected Front Range Province of the Colorado Rockies. The district ranges in altitude from 5,500 to 8,750 feet. It is near the northeast end of the Colorado mineral belt, which extends across the Colorado Front Range from Boulder and Jamestown southwestward to Breckenridge and Leadville. Gold telluride was discovered in 1875, and since then there has been an intermittent production of gold and silver, with an unofficial aggregate value of approximately $3,000,000. Small amounts of tungsten were mined during the World War.

GENERAL GEOLOGY.

The Magnolia district is almost entirely within the pre-Cambrian complex of the Front Range. Algonkian (?) granite gneiss and accompanying pegmatites and aplites cover the major part of the district. Upper Paleozoic and lower Mesozoic sedi-

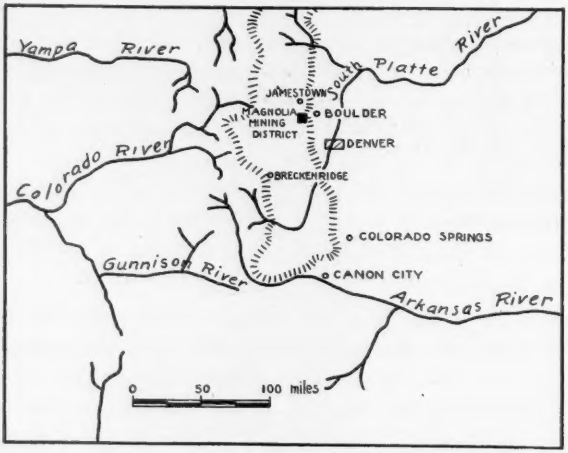

FIG. 1. Index map of Colorado showing location of Magnolia district.

ments flank the pre-Cambrian crystalline rocks in the extreme eastern part. A late Cretaceous quartz diabase dike trends northwestward across the western half of the district. Intruded into the Paleozoic sediments are sheets of rhyolite porphyry of early Eocene (?) age.

Pre-Cambrian.—The Boulder Creek granite gneiss of Algonkian (?) age covers almost all of the district west of the foothills. The gneiss is medium-grained, grey to pink in color, and is composed essentially of quartz, feldspar, and biotite. It is believed to be a primary gneiss whose oriented tabular feldspar and biotite indicate the direction of movement of the magma just preceding consolidation. Pegmatite and aplite dikes, mostly less than 15 feet wide and few extending more than 2,000 feet, are numerous.

Pennsylvanian.—Resting unconformably upon the granite gneiss in the eastern part of the district are the conglomerates, sandstones, and arkose of the Fountain formation, whose thickness varies from 500 to 1,500 feet within 4 miles along the strike. The Fountain formation dips eastward at about 50° and forms the "Flatirons" of the foothills.

Late Cretaceous and Early Eocene (?).—The "Iron Dike," a strongly magnetic quartz diabase, trends northwestward across the western part of the district and continues about 30 miles to beyond Estes Park, but contains little or no quartz in most places outside the Magnolia district. The dike varies in width from a few feet to a maximum of 50 feet. It has no apparent relation to the ore deposits.

About 100 feet above the base of the Fountain formation are two intrusive sheets of rhyolite porphyry. The longest sheet extends northward from Gregory Canyon to approximately one-half a mile south of Boulder Creek. The sheet varies in width from 10 to 60 feet. The walls locally are altered by slight induration. Evidence found elsewhere indicates these intrusives appeared during the Laramide revolution.

STRUCTURE.

Regional Structure.—The regional structure of the Colorado Front Range has been summarized by Lovering.[1] The Front Range gained its present outline as a result of the Laramide revolution. Regional compression from a northeast-southwest direction during this time folded and faulted parts of the range, especially in the foothills region. Folds and faults of northwesterly trend are common along both borders of the range. Along the east side, especially from the Wyoming line south to Boulder Creek, en echelon flexures of northwesterly trend become more numerous and more closely folded and faulted. In Boulder County these faults are abundant and have steep dips with the downthrown side on the west. Three of these faults pass through the Magnolia district. Westward- to west-northwestward-trending reverse faults of probably the same age also occur. They dip steeply northward.

Shortly after the formation of these faults a northeast belt of porphyry stocks was intruded in the western half of Colorado, extending across the Front Range from the vicinity of Boulder southwestward to Breckenridge and Leadville. These stocks are believed to be approximately parallel with the deforming force of the Laramide revolution.[2]

Local Structure.—Detailed study of the Boulder Creek granite gneiss within the Magnolia district and a reconnaissance of the batholith as a whole indicate that the gneiss is primary and that the magma ascended at a steep angle several miles north of the Magnolia district, and spread laterally largely to the south.[3]

In the eastern extremity of the district the northward-trending foothills monocline of Pennsylvanian and later sedimentary rocks

[1] Lovering, T. S.: The structural relation of the porphyries and metalliferous deposits of the northeastern part of the Colorado mineral belt. Ore Deposits of the Western States, pp. 301–305. A. I. M. E., 1933.

[2] Lovering, T. S.: Geology and ore deposits of the Montezuma Quadrangle, Colorado: U. S. G. S. Prof. Paper 178: 304, 1935.

[3] Wilkerson, A. S.: Geology and ore deposits of the Magnolia mining district and adjacent area, Boulder County, Colorado. Colorado Sci. Soc., Proc. in press.

dip on an average of 50° eastward, although locally they are vertical and even overturned.

Several nearly vertical fault zones trend diagonally northwestward across the district and continue for a number of miles. At least two of these faults are traceable southeastward to echelon faults in the foothills. They are known as the Green Mountain and Boulder peaks faults, and deflect the igneous-sedimentary contact westward. The northwestern extensions of these faults into the gneiss area are known as the Maxwell and Hoosier faults or "breccia dikes," respectively. A third and parallel fault, known as the Livingston "breccia dike," is just west of them. Two westward- to west-northwestward-trending faults, known as the Red Sign and Copeland faults, of about the same age also occur. They dip steeply northward. All are of the reverse type with a strong horizontal component of movement.

These fault zones range in width from 10 to 70 feet and are marked by highly silicified and iron-stained, fractured, and brecciated gneiss, pegmatite, and aplite. Under the microscope, mortar, flaser, and mylonitic structures are common. Repeated fracturing occurred, and at least three periods of barren mineralization are recognized in them.

There are in the Magnolia district two major systems of fault fissures that are occupied by the ore deposits—a west to northwest system, which is in general the earlier, and an east to east-northeast system. Both are largely confined to the northwest part of the district and are at or close to one of the major fault zones. The northwest system is mineralized with tellurides, the northeast with tungsten, and the common east-trending fissures locally contain either telluride or ferberite or both. The veins dip steeply north and south and are mineralized portions of both normal and reverse faults that have had a strong horizontal component of movement. Both systems of metallized faults are later in age than the strong persistent northwest silicified fault zones.

ORE DEPOSITS.

Mineralogy and Paragenesis.—The gold telluride fissure zones contain several telluride minerals, chalcedonic quartz, disseminated pyrite, and small amounts of native gold, sphalerite, marcasite, fluorite, and calcite. Sylvanite is the main ore mineral and is generally accompanied by one or more of the following tellurides; calaverite, hessite, petzite, coloradoite, altaite.

The various tellurides are in blades that average about 1.5–2.5 mm. in length and .5 mm. in width and in many places are so abundant that they resemble single large prismatic crystals. The fissures range in width from an inch to 4 feet. The fissure zones commonly consist of several narrow seams of telluride minerals; seldom does the ore occur in a single vein. The seams generally are one-sixteenth to half an inch wide, although some several inches wide are found.

The tungsten fissures contain ferberite, chalcedonic quartz, pyrite, sphalerite, and locally a small amount of alunite. Ferberite is the only known tungsten-bearing mineral in the district and is found in blades that average about .2 mm. long by .1 mm. wide. The fissures range in width from an inch to about 5 feet. At several places the fissures contain a single vein, but commonly they have several that are a quarter of an inch to 3 inches wide.

Three generations of ferberite are recognized. The early coarse-grained ferberite was contemporaneous with or slightly earlier than the tellurides, and both were then followed by a wave of nearly pure ferberite mineralization. This generation of ferberite was fine-grained and was succeeded by contemporaneous fine-grained quartz carrying a small amount of ferberite and minor amounts of pyrite.

Briefly summarized, the order of mineral deposition is believed to be as follows: (1) quartz; (2) quartz and hematite; (3) quartz; (4) quartz, pyrite, marcasite, sphalerite; (5) fluorite (?); (6) calcite (?); (7) quartz, pyrite, alunite, ferberite; (8) tellurides and native gold; (9) ferberite; (10) quartz, ferberite, pyrite.

The telluride-native gold sequence of mineralization is believed to be as follows:

Mineral.	Chemical Composition.
1. Sylvanite	$(Au\ Ag)\ Te_2$
2. Calaverite	$(Au\ Ag)\ Te_2$
3. Petzite	$(Au\ Ag)_2\ Te$
4. Hessite	$Ag_2\ Te$
5. Coloradoite, altaite	Hg Te Pb Te
6. Native gold	Au

In no vein is the complete telluride sequence found. Each telluride is replaced by a succeeding one in the series (Figs. 3, 4, 5). The exact relationship between coloradoite and altaite is not known. Specimens that contain native gold were not obtained, but one from a near-by similar deposit shows that gold replaced hessite and petzite (Figs. 6, 7). There is no evidence that native gold did not precede coloradoite and altaite, however.

Wall Rock Alteration.—Silicification and sericitization are the main hypogene processes that have affected the wall rocks of the ore deposits. Sericitization was accompanied and followed by silicification. Pyritization occurred locally after the second period of silicification. Hypogene alteration has, however, been slight throughout the district.

In the wall rocks of the telluride veins, silica was deposited close to the veins in largest quantities. There the introduced quartz, commonly in small veinlets, makes up about 10 per cent of the rock. The silicification extended from a few inches to about 2 to 3 feet from the veins. Finely disseminated pyrite and small stringers of pyrite are found at some places within the zone of quartz introduction, but the two zones are not necessarily coextensive. The amount of pyrite seldom exceeds 1 per cent. The zone in which much sericite was formed includes and extends beyond the limits where silicification took place. The greatest amount of sericite was formed within 3 to 4 feet of the veins. Close to the veins, the acid plagioclase was converted almost completely to sericite, but microcline was unaltered. Carbonization was coextensive with that of sericitization outside the zone of

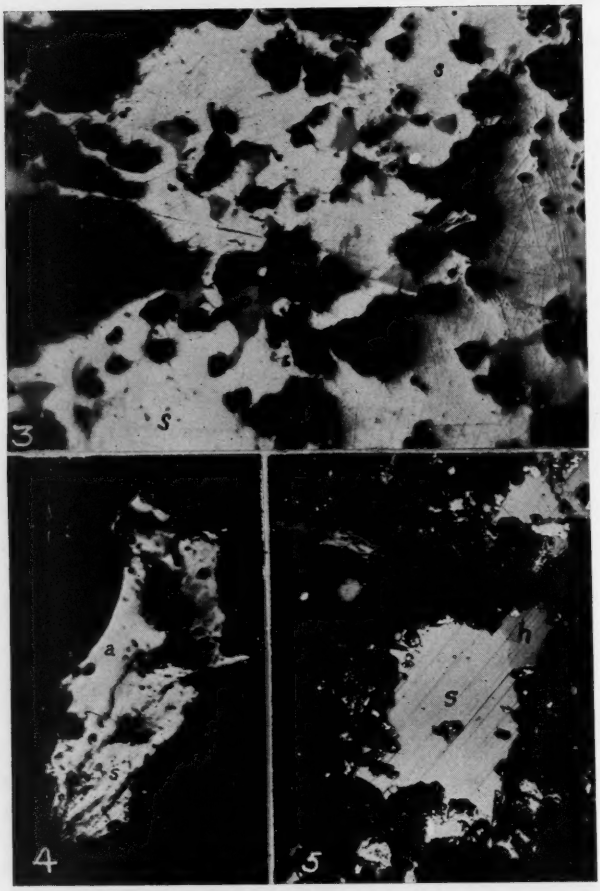

FIG. 3. Telluride ore from Keystone mine. Petzite (*p*) replaces sylvanite (*s*); black is quartz. × 127.

FIG. 4. Telluride ore from Keystone mine. Altaite (*a*) replaces sylvanite (*s*); black is quartz. × 127.

FIG. 5. Telluride ore from Eclipse mine. Hessite (*h*) replaces sylvanite (*s*); black is quartz. × 68.

quartz introduction. The wall rocks are altered to a greater degree close to the wide veins than close to a narrow vein, and adjacent to ore shoots the alteration generally is more extensive than at a distance from them.

In the wall rocks of the tungsten veins, silicification took place close to the veins, and locally 80 per cent of the wall rock is introduced quartz. Seldom is this quartz found at a distance greater than 1 to 2 feet from the vein. Acid plagioclase was almost completely altered to sericite near the veins, but potash feldspar was unaltered. Sericitization occurred largely outside the zone of silicification.

Enrichment.—Partial oxidation extends to a depth of at least 200 feet beneath the surface. Although secondary enrichment of the telluride ores—by the leaching of tellurium and probably of some silver—was of importance in the oxidized zone, supergene deposition of gold was not recognized in any of the deposits visited. The writer was shown numerous specimens of "rusty" gold in porous quartz which were collected during the early days of the camp. Much of the rich ore then mined was said to have been "rusty" gold found at or close to grass roots. Oxidation has had no visible effect on the tungsten deposits.

Localization of Ore.—Gold and tungsten are localized in shoots and pockets and show a marked lack of persistence. Concentration took place in openings that were dependent upon structural features; junctions of fissures, and irregularities of the fissures coupled with pre-mineral movement. The chemical composition of the wall rock had no influence on the localization of ore. The greatest proved range of gold ore and tungsten ore in an ore shoot is about 400 feet and 100 feet, respectively, but the vertical range of ore deposition is much greater; gold deposition occurs through a minimum vertical range of 1,600 feet and that of tungsten about 1,250 feet.

Origin of Ore.—It has previously been stated that a belt of stocks occurs in the Front Range from Jamestown to Breckenridge. Since the mineral and porphyry belt coincide, a genetic relation of the ore deposits to these porphyries has long been

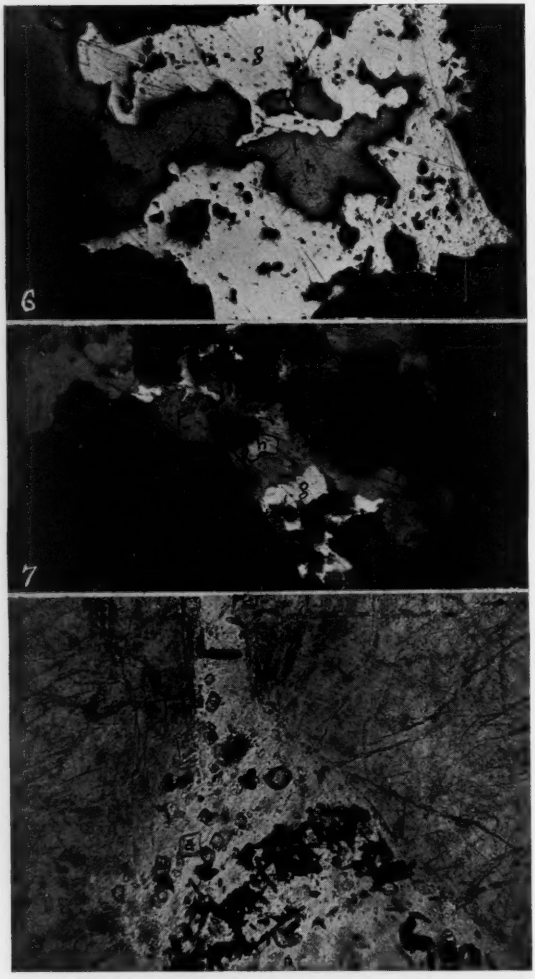

FIG. 6. Telluride ore from Logan mine. Gold (*g*) replaces hessite (*h*); black is quartz. ×68.

inferred. In the Breckenridge district [4] the hypogene mineralization was directly related to the solidification of the quartz monzonite porphyry. In the Jamestown district [5] the ores are genetically related to the compound Tertiary intrusions of granodiorite and quartz monzonite. Because the ore-filled fissures in the Magnolia district lie within the mineral belt, and because the minerals of the fissures are those generally associated with deposits that are of proved magmatic origin, the ores of the district are believed to have been deposited by emanations from an underlying early Tertiary magma.

Only the strong westward- and northwestward-trending breccia fault zones were affected by the early barren stage of mineralization. These faults served as passageways for the ascending solutions that silicified the zones. With continued stresses the silicified zones were locally reopened, and new short fractures were created approximately paralleling them. The breccia fault zones were tightly silicified and almost closed at the end of the period of barren mineralization, and the solutions that continued to rise found conditions favorable for deposition only where channels had been reopened within the silicified faults or where fissures had been formed near-by. On their journey from the magma toward the surface the ore solutions took the paths of least resistance, rising as best they could along the deep-reaching, persistent but relatively tight breccia fault zones. In them only an insignificant amount of gold telluride mineralization took place, but in the fissures newly formed near-by important amounts of the tellurides were deposited.

[4] Lovering, T. S.: Geology and ore deposits of the Breckenridge mining district, Colorado: U. S. G. S. Prof. Paper 176: 24, 1934.

[5] Goddard, E. N.: The influence of tertiary intrusive structural features on mineral deposits at Jamestown, Colorado: ECON. GEOL., 30: 373, 1925.

FIG. 7. Telluride ore from Logan mine. Gold (*g*) replaces petzite (*p*), which is replaced by hessite (*h*); black is quartz. × 68.

FIG. 8. Photomicrograph of a portion of Copeland fault. Fine-grained quartz (*q*) contains ferberite (black) and alunite (*a*) in a vein that cuts granite with numerous small fissures filled with iron oxides (*h*). Parallel nicols. × 100.

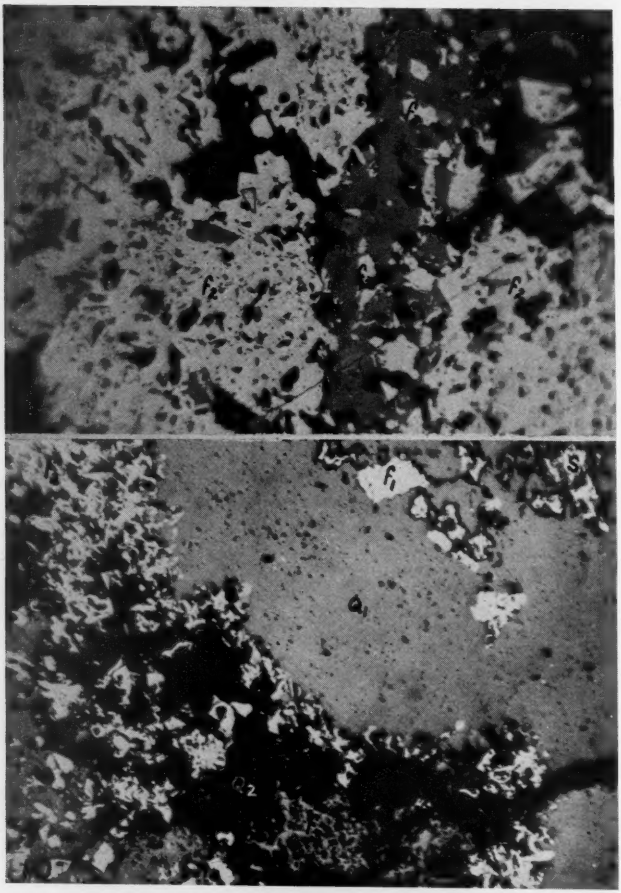

FIG. 9. Tungsten ore from Kekeonga mine. Ferberite of second generation (f_2) cut by quartz and ferberite of third generation (f_3). × 125. By T. S. Lovering.

FIG. 10. Telluride-tungsten ore from Kekeonga mine. Sylvanite (s), quartz (q_1) and ferberite (f_1) of first generation; quartz (q_2) and ferberite (f_2) of second generation; and ferberite (f_3) of third generation. × 125. By T. S. Lovering.

Throughout the district the north walls moved west. This shearing again reopened portions of the eastward-trending breccia faults and also opened new, short, eastward- and east-northeastward-trending fissures into which ferberite was introduced. The compression that formed the strong silicified faults probably continued for some time in the vicinity of Magnolia, but the direction of the stresses seemingly changed from the northeast more to the east or slightly north of east. Lovering [6] recognizes the importance of these changing stresses in respect to the formation of the fissures throughout the tungsten belt in Boulder County.

The lack of persistence of most of the fissures, and therefore of the mineral deposits that fill them, indicate rupture under slight load. The fineness of grain of both ore minerals and gangue is doubtless a direct expression of the rapidity with which saturation was attained and crystallization induced by rapid loss of temperature and pressure close to the surface. Flaser structure and undulose extinction of the quartz grains in parts of the breccia fault zones are suggestive of deformation at shallow depths. Other facts that point to a comparatively shallow origin of the deposits include: the abundance of vugs, the drusy structure of parts of the veins, chalcedonic quartz, the presence of marcasite and alunite, and the total absence of heavy silicate gangue minerals and large amounts of sulphides. The ores probably formed near the lower part of the epithermal zone, and it is probable that the highest parts of the present surface are not more than 3,000 feet below the surface that existed when the ores were formed.

The stocks of the mineral belt are younger than the folding and faulting of the Laramide revolution but are older than the Flattop peneplain of lower Eocene time,[7] and were probably intruded about the beginning of basal Eocene time. The ore deposits of the mineral belt are believed to be of basal Eocene age or slightly

[6] Lovering, T. S.: The structural relations of the porphyries and metalliferous deposits of the northeastern part of the Colorado mineral belt; Ore Deposits of the Western States, p. 306, A. I. M. E., 1933.

[7] Lovering, T. S.: Geology and ore deposits of the Montezuma Quadrangle, Colorado: U. S. Geol. Surv. Prof. Paper 178: 51, 1935.

younger, and those of the Magnolia district are probably the same age. The late Cretaceous or early Eocene pitchblende deposits at Black Hawk, Gilpin County, Colorado are thought to be about 60,000,000 years old.[8]

RUTGERS UNIVERSITY,
NEW BRUNSWICK, N. J.,
March 1, 1939.

[8] Holmes, Arthur: Radioactivity and geologic time: Nat. Res. Coun. Bull. 60: 347, 1931.

SLATES OF EAST TENNESSEE.[1]

H. C. AMICK.

ABSTRACT.

The possible commercial slates of East Tennessee are associated with conglomerates of the Unaka Mountains which belong to the early Cambrian Ocoee series. These are limited to the SE and NW by faults. The Ocoee rocks can be distinguished from the Pre-Cambrian crystalline rocks to the southeast by their lesser metamorphism.

There are three slate horizons in the Ocoee series, but slate of commercial qualities is confined to the Pigeon formation. Much of this is strongly jointed and impregnated with marcasite; consequently quarry sites must be carefully selected. However, there are some capable of yielding good structural slate with a variety of colors, as well as material suitable for rustic shingles and an excellent grade of granules for composition roofing.

The first quarrying was on Panther Creek in the Little Tennessee River district, about 1895, for blue-gray and purple slate shingles. Later, others were opened, unsuccessfully, until 1920, when one near the Tellico River was operated for eight years producing granules. In 1932 quarries were reopened on Panther Creek, for structural slate, for various uses. Certain horizons within the Pigeon slate formation are well suited to this type of development and appear to have good future possibilities.

THE slate formations of East Tennessee, which appear to have commercial possibilities, occur on the northwest slopes of the Unaka Mountains and southeast of the fault that determines the southeast front of Bean, Chilhowee, and English Mountains. From the Georgia-Tennessee line to the vicinity of the French Broad River, east of Newport, Tennessee, they outcrop in irregular belts. The topography of this area is rough and irregular, due to the fact that the major streams cut directly across the hard and soft strata; and in many places have entrenched themselves in deep and narrow gorges, while their tributaries are

[1] Published by permission of Tennessee Geological Survey. Presented before the Society of Economic Geologists, Knoxville Meeting, Oct., 1938.

consequent and have cut deeply along the zones of soft or broken rocks.

These slates are associated with massive beds of conglomerate and belong to the Ocoee series, which is referred to by Keith in the Knoxville Folio [2] and Hayes in the Cleveland Folio [3] as a metamorphic group of unknown age (Fig. 1). However, more re-

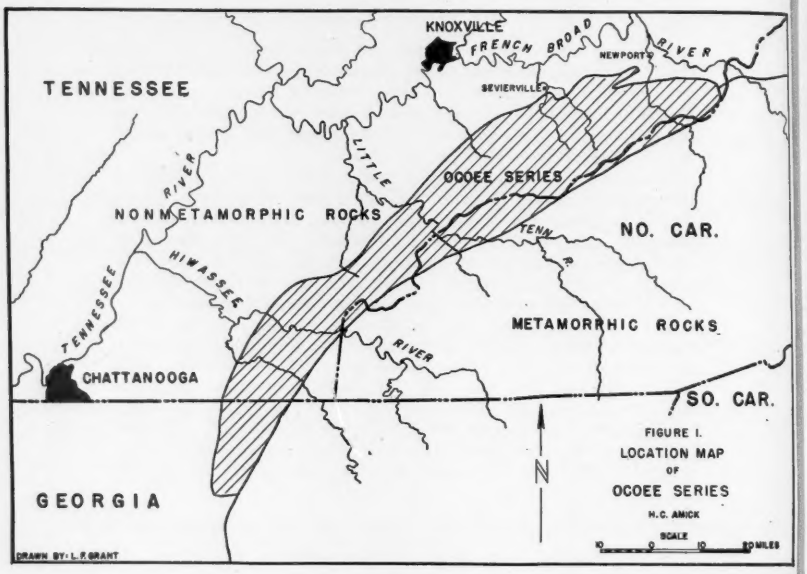

FIG. 1.

cent investigation by Crickmay,[4] Moneymaker,[5] and others indicate that this series is of early Cambrian age. Fossils are not found in these rocks, all traces seeming to have been destroyed

[2] Keith, Arthur: U. S. Geol. Surv., Geological Atlas, Knoxville Folio, No. 16.

[3] Hayes, C. W.: U. S. Geol. Surv., Geological Atlas, Folio No. 20.

[4] Crickmay, G. W.: Status of the Talladega Series in southern Appalachian stratigraphy. G. S. A. Bull. 47: No. 9, 1936.

[5] Moneymaker, B. C.: Character of the Great Smoky formation in the Hiwassee river basin of Tennessee and North Carolina, Tenn. Acad. of Sci. Jour., XIII: No. 4.

by metamorphism, if they ever existed. Due to the fact that these rocks were laid down in close proximity to an old shore line, the formations have few constant characteristics. They have also undergone lithological changes that add to the difficulties of making accurate correlations.

The rocks of the Ocoee series are separated from the non-metamorphic formations to the northwest by a great thrust fault, which, in the opinion of the writer, is a continuation of the Cartersville fault, that was described by Hayes.[6] On the southeast the Ocoee rocks are separated from the Great Smoky formation by a thrust fault.[7] The Great Smoky formation is included in the Talladega series by Crickmay.[8] Both Crickmay[9] and Moneymaker[10] have pointed out that the rocks of the Great Smoky formation belong to the highly metamorphosed groups and have undergone two separate periods of metamorphism, while those of the Ocoee series have undergone only one period of metamorphism. Safford[11] recognized this fact and referred to the rocks that Crickmay[12] has classified as the Talladega series, as metamorphic or crystalline rocks. He suggested the name "Ocoee" for a group at the bottom of his Knox division; and in his description referred to them as slightly metamorphosed.

The outstanding formations of this series as listed by Keith in the Knoxville Folio[13] are Clingman conglomerate, Hazel slate, Thunderhead conglomerate, Cades conglomerate, Pigeon slate, Citico conglomerate and Wilhite slate.

The conglomeratic formations vary in thickness from 50 to 3,000 ft. and contain the dominant beds of the area, which have had a profound effect in determining the structure of all the formations of the area. They are composed of siliceous deposits

[6] Hayes, C. W.: The overthrust faults of the Southern Appalachians. G. S. A., Bull., vol. 2, 1891.

[7] Moneymaker, B. C., Op. cit.

[8] Crickmay, G. W., Op. cit.

[9] Crickmay, G. W., Op. cit.

[10] Moneymaker, B. C., Op. cit.

[11] Safford, J. M.: Geology of Tennessee, Nashville, 1869.

[12] Crickmay, G. W., Op. cit.

[13] Keith, Arthur: Op. cit.

that vary from fine white sand to coarse quartz conglomerate. The majority of these beds were laid down near ancient shore lines as arkosic materials, and were slightly metamorphosed during the Appalachian orogenic movement. Due to their great thickness and siliceous nature, these formations are resistant to erosion and form some of the high points of the area.

The Hazel slate occurs in several places along the North Carolina-Tennessee line. It is approximately 700 ft. thick (according to Keith) [14] and is composed of black slate and thin beds of sandstone and conglomerate. The black color is mainly due to large amounts of graphitic material and black oxide of iron. There are many places in which this slate contains large quantities of small particles of marcasite which leave brown iron stains on exposed surfaces.

The Wilhite slate is the lowest formation of the Ocoee series. It is a bluish-gray or black argillaceous slate that cleaves readily and commonly contains dark blue massive lenses of limestone and conglomerate in its upper portions. Its thickness varies from a few feet to 800 ft. with an average thickness of 300 or 400 ft. (according to Keith).[15] As a rule it outcrops in the lower parts of the mountains to form bands around the coves. Throughout a great part of this formation it has been impregnated with marcasite, which greatly aids in rapid disintegration when it is exposed to weathering.

The Pigeon slate formation is comparatively constant throughout the area. In thickness it varies from 1,300 to 1,700 ft. (according to Keith).[16] The predominant color is bluish-gray, but large outcrops of pale green and purple slate are common through its entire extent and in a few places red beds have been observed. Small crystals of feldspar are found distributed through this slate, as a rule being small enough to escape notice, but in some places they are large enough to give cleavage surfaces a bumpy appear-

[14] Keith, Arthur: Op. cit.
[15] Keith, Arthur: Op. cit.
[16] Keith, Arthur: Op. cit.

ance or leave a pitted surface after weathering. A large portion of this formation is found to contain zones that are impregnated with fine particles of marcasite, which leave the slate in a spongy, iron-stained condition when it is exposed to weathering. However, by careful selection it is possible to locate horizons within this formation that have small amounts of marcasite and resist erosion exceptionally well. In the majority of places the bedding may be determined by variations in color and by slight changes in texture and composition. Joint systems are well developed in this formation as a result of crustal movements that have occurred since the rocks were metamorphosed and in restricted areas they are so badly broken that it is hard to determine the directions of the major joints. Throughout the entire formation there is a tendency toward the development of incipient joint planes that meet each other at a high angle and may cause the slate to break into triangular blocks when hit with a hammer.

The Wilhite and Hazel slate formations of this series have very little if any commercial value. However, the Pigeon slate formation contains good splitting beds of bluish-gray, dark blue, light and medium green, and several shades of purple slate that is of commercial value if properly developed.

The first attempt at slate quarrying in East Tennessee was about 1895 in the Little Tennessee River district. At this time the Chattanooga Slate Company opened three quarries along Panther Creek for the purpose of obtaining roofing slates. These quarries were located high on the sides of the valley where the drainage was excellent, the overburden was thin (being about 5 ft.) and it was possible to bring all the slate produced to the road in the valley by gravity. The slates produced were of two colors, blue-gray and purple. They were brought down the creek on an old lumber tram road, that has since been removed. The majority of these slates were shipped to Chattanooga to be used as roofing slates. However, a small amount was used in Maryville, Tennessee.

About 1900, another slate quarry was opened in the Little Ten-

nessee River district for the purpose of obtaining roofing slates. This quarry was opened on the Hamilton property and produced blue-gray slates that were exceptionally uniform in appearance, but due to the presence of marcasite this quarry did not prove to be profitable.

In 1906 the Locket and Price Slate Company opened a slate quarry in the Little River area on the Tipton property near the head of Short Creek, for the purpose of producing roofing slates. The slates produced at this place were a uniform greenish-gray shingle with a brilliant luster, but due to the presence of marcasite careful selection was necessary in order to prevent fading and brown iron stains.

About 1910 a slate quarry was opened near Tellico Plains on Laurel Creek, by C. F. Herfferd, for the purpose of producing roofing slates. Both green and purple slates were produced and judging from the material on the dump heap these slates should resist weathering and fade very little.

In 1920 J. B. Preston opened a pit in the Tellico Plains area on Laurel Creek to quarry green slate for granules. He operated it for a short time, then sold it to the Tennessee Rocks Products Company, who operated the open pit for only a short time, when they changed the method of operation to underground mining. This method was continued until the fall of 1928, when the mine was closed as a result of exhaustion of material of desired characteristics and legal difficulties regarding the method of disposing of waste materials.

There are several other slate prospects in the area occupied by the Pigeon slate formation, some of which appear to have commercial possibilities but due to a limited demand, have not been developed.

In 1932 Mr. J. T. Roberts, who has had experience with slate in Vermont and Georgia, came to East Tennessee. After prospecting the area for some time he started developments in the Little River and Little Tennessee River districts. However, his endeavors in the Little Tennessee River district have been more promising. One of the quarries that is near the head of Panther

Creek appears to have good possibilities for producing high grade, dark blue roofing slates, but it has the disadvantage of being the most inaccessible one. After several attempts to produce roofing slates he turned to the production of structural slate. The carefully selected, large angular blocks can be shaped to meet the demands of various uses. During the past three years his results have been encouraging and it appears that there are good possibilities for structural slate in East Tennessee, which is fortunate due to the fact that it is a great marble producing area and the marble companies often receive orders that require some slate.

Samples of slate taken from Mr. Roberts' Panther Creek quarry were examined by the Nichols Chemical Laboratory in Knoxville, and the following analysis obtained.

	Per cent
Silica	58.45
Iron	10.22
Aluminum oxide	18.38
Calcium oxide	00.80
Magnesium oxide	03.15

The structural slate shows graining exceptionally well and can be used successfully in its natural shapes for flagstones, walks, terraces, stepping stones, coping, benches, markers, and bulkheads. It may also be manufactured or processed and used for bases, flooring, wainscoting, partitions, table tops, mantles, mausoleums, sills, treads, platforms, furniture, and hearth stone. The slate is produced by local labor, which eliminates undesirable labor problems, due to the fact that the men spend the time when they are not employed in the slate quarry on their mountain farms or hunting.

After studying the characteristics of the Hazel, Wilhite, and Pigeon slate formations as well as observing prospect pits and quarries, it is obvious that the commercial slate possibilities of East Tennesse are to be found in carefully selected quarry sites located on the Pigeon slate outcrops. Structural slates that have a variety of uses appear to hold the best possibilities for future development. However, there are quarry sites that have excel-

lent possibilities for the production of large quantities of slate granules of excellent quality and a variety of colors, as well as crushed slate that could be used as fillers. The future possibilities of shingles from this area appear to be largely confined to those that are irregular in shape, thickness, and color, and that can be used with a high type of architecture when a rustic appearance is desired. It may also be suggested that when the southeastern states develop their potential industrial areas, such as the Great Valley of East Tennessee, there will probably be an increase in the demand for flagging to be used in beautifying lawns and private estates.

UNIVERSITY OF TENNESSEE,
KNOXVILLE, TENNESSEE,
March 2, 1939.

DISCUSSION AND COMMUNICATIONS

TEXAS SURFACE SOILS.

Sir: During recent studies with wind-blown sands from Lynn and Lubbock counties, in West Texas, the iron staining commonly found was examined. Fifty grams of unsieved dune sand were boiled sixty minutes in hydrochloric acid in the presence of potassium chlorate, and the quartz grains were removed from the resulting liquid. The iron was precipitated from solution, filtered off, and dried by baking. The final weight of the iron was .74 grams, or 1.48 per cent by weight, of the original sand.

Examinations of individual, measured quartz grains showed that most of the iron occurs on the larger sizes where, in places, it stains as high as thirty per cent of the grains. Since the soils in these two counties are deficient in iron, it is difficult to account for the high iron content of sands derived from these same soils. Heavy, iron-bearing accessory minerals may be a source, but they occur in quantities hardly commensurate with the amount of iron staining present. The presence of roots in the soils, and the absence of vegetable matter in the sands, may account for the concentration of iron in the dunes.

Harder [1] states that decaying vegetation in iron-bearing sands leaches out the iron for several inches in each direction from the root, leaving the grains free of stain. If this is the cause of bleaching in West Texas dunes, then the iron is residual, having been leached to lower levels in the subsoil, and not being seen again at the surface until a " blow-out " during a dry season gives rise to dune formation and the consequent turning-over of the soils and subsoils.

The surface soils of the High Plains of West Texas were introduced from New Mexico by running water and the wind. It is thought that they are the products of the erosion of a chain of

[1] Harder, E. C., U. S. Geol. Surv. Prof. Paper 113, p. 47.

mountains that formerly extended southward from Colorado. The iron was introduced simultaneously with the soils, as is indicated by the three hundred feet of red flood-plain, river, and dune deposits underlying the surface of the High Plains. Present distribution of the iron is due to the presence (or rather absence) of a relatively thick cover of plant life.

Those soils that have been observed to blow readily contain the greatest amount of iron, whereas those soils that are stable, and for that reason more suited to agriculture, are notably poor in iron.

In certain undisturbed areas, then, one layer of clastic sediments some distance below the surface is gradually acquiring a large per cent of reddish iron hydroxide. It is suggested that this method of coloring may have given rise to other red minor sediments underlying semi-arid regions.

WILLIAM F. TANNER.

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LUBBOCK, TEXAS,
March 8, 1939.

"THE GOLD MISSUS."

Sir: The August, 1938 issue of ECONOMIC GEOLOGY contains a review of a book, "The Gold Missus," by Katherine Fowler-Lunn. The book is an interesting and well-written account of a courageous venture, and from the author's personal connections alone will probably reach a wide geological and mining public in the United States and West Africa. The writing of such a book for lay readers probably necessitates omissions of many features. Two of these, however, are somewhat unfortunate; one, the wrong impression given in the book of the development of Sierra Leone as a mineral producer, and, the other, the injustice done to the Sierra Leone Geological Survey, and in particular to the then Director, Dr. N. R. Junner.

Although her opportunity to work, with official approval, in West Africa was due to Dr. Junner, the work of the Survey was

almost completely ignored, and Dr. Junner's striking discoveries are casually mentioned as the finding of "traces" of gold, iron ore, platinum, chromite, etc. The present writer was engaged for lengthy periods from 1928–1930 in following up some of these discoveries on behalf of a West African Company, and has no hesitation in describing them as an outstanding example of the value of applied geology in the location of mineral deposits. In the case of gold, diamonds and iron ore they have initiated important industries and immensely improved the economic outlook for Sierra Leone. An opportunity was missed of emphasizing the value of economic geology to a wide public.

T. HIRST.

GOLD COAST GEOLOGICAL SURVEY,
PRESTEA, GOLD COAST.

REVIEWS *

Mine Examination and Valuation. By C. H. BAXTER AND R. D. PARKS, with an appendix on Michigan Mine Appraisal System by FRANKLIN G. PARDEE, 2nd Edit. Published by C. H. Baxter and R. D. Parks, Michigan College of Mining and Technology, Houghton, Mich., 1939.

The second edition of this book will be welcomed by all who are concerned with instruction in the principles of mine valuation. The new edition follows closely the plan of the first one, but the treatment of many subjects has been improved by thoughtful revision. The book is written primarily for engineers and engineering students, and the geological factors pertinent to mine examination are left in large part to other books. Professors Baxter and Parks are primarily concerned with mines whose ores can be appraised with little appeal to geologic doctrine. This attitude, and indeed the whole book, reflects the extensive experience of the authors in the Lake Superior mining districts, but the western miner will probably feel that some of his problems are slighted and an overemphasis placed on those of iron deposits.

Part I (pp. 1–100) discusses problems of mine examination. The book begins with brief sections on the purpose and scope of examinations, the qualifications and responsibility of the examining engineer, the conduct of the examination, and preliminary phases of the examination. They are followed by a somewhat more detailed treatment of sampling. This section has been thoroughly revised, and though necessarily somewhat brief, the reviewer feels that if it is supplemented by readings from the bibliography at the end of the book, it will be found very satisfactory. The remainder of Part I deals with ore estimation, assets other than ore, economic considerations, estimates of future profits, and the preparation of the report. Only a few changes have been made in this portion, but all the sections have been brought up to date. The discussion of economic considerations and their effect upon valuation is outstanding. It is a brief but remarkably clear exposition of a difficult subject.

Part II is devoted to the financial theory of mine valuation. The mathematics of compound interest, annuities, amortization, and redemp-

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

tion annuities is well presented and used as a foundation for deriving mine valuation formulas. This material is better arranged in the second edition, but is essentially the same in content as in the first. The discussion of interest rates has been enlarged and revised in the light of recent world-wide changes in economic conditions. The addition of the section on valuation of an undeveloped property is very welcome and should crystallize much of the theory into usable form for students.

Part III is made up of valuation tables indispensable to all who use mine valuation formulas.

Part IV is a clear statement of the Michigan Mine Appraisal System for tax valuation and is written by Franklin G. Pardee. It should be read with interest and profit by all who are interested in the problem of state or federal revenue from mineral properties. An extensive and up-to-date bibliography which includes references as late as 1938 completes the book.

The volume deserves a place in the library of all professional mining engineers and mining geologists, and most teachers will probably agree with the reviewer that it is unusually well suited to the needs of the student.

T. S. LOVERING.

UNIVERSITY OF MICHIGAN,
ANN ARBOR, MICH.,
April 21, 1939.

Practical Seismology and Seismic Prospecting. By L. D. LEET. Pp. 430; Figs. 183. D. Appleton-Century Co., New York, 1938. Price $6.00.

This is another of the Century Earth Science Series volumes. Four of the five parts of this book deal with earthquakes under cause, distribution, elasticity and elastic waves, instrumental methods and descriptive observations including terminology, effects, examples, mechanics and history. It is the most comprehensive study of earthquakes yet written and it is not too mathematical to deter the interested reader. It presents modern methods of investigating rock structure, and acquaints the reader not only with the theoretical side but points toward the practical aspects of geological investigations.

Part V deals with seismic prospecting, both refraction and reflection. The methods are described, procedure of reduction of observations is given, and commercial applications are considered.

The book is comprehensive, authoritative, and will be particularly valuable to all interested in earthquake phenomena and commercial seismic prospecting.

ALAN BATEMAN.

Die Bergwirtschaft der Erde. Bodenschätze, Bergbau und Mineralienversorgung der Einzelnen Länder. By F. FRIEDENSBURG. Pp. xv + 504. Figs. 40. Ferdinand Enke Verlag, Stuttgart, 1938. Paper. Price, 30 Marks.

Because nearly the entire thought of nations is becoming more and more concerned with the question of raw materials, especially those of mineral origin, the author thought it advisable at this time to offer a survey of mineral resources of the world and their distribution among the various countries, their colonies and their mandated areas. There is nothing especially new in the volume, but the author's work is well done. He has presented a compact survey of the mining industry and the present mineral production of 160 different geographical entities, and has stated what is known of their probable reserves. Though the book is well documented with citations of articles dealing with the areas discussed, there seem to be few references to those written in the language native to many of the countries dealt with.

The book is not argumentative. It is almost exclusively factual and is consequently a convenient guide to the literature dealing with the world's mineral resources. In it are 40 sketch maps of the more important countries showing the locations of their producing areas and 139 statistical tables.

W. S. BAYLEY.

Annotated Bibliography of Economic Geology: General Index, Vols. I–X, 1928–1938. Pp. 496. Economic Geology Pub. Co., Urbana, Ill., 1939. Price, $5.00.

Although this volume is listed as an index to the last 10 volumes of the Annotated Bibliography, it really serves as an up to date, 10-year index to the entire subject of economic geology throughout the world. If one desires to look up manganese, for example, he finds two pages of entries, referring to manganese deposits in 34 different countries, to all the manganese minerals, to deposition, types of deposits, enrichment, oxidation, reserves, and mineralographic identification. Similarly, under petroleum are 13 pages of entries relating to petroleum of all districts in the world. References to the individual volumes of the Bibliography will give an abstract of the subject. It is a volume the geologist cannot afford to be without.

Spot Tests. By FRITZ FEIGL, trans. by JANET W. MATTHEWS. Pp. 400; Figs. 24; Tables, 31. Nordemann Pub. Co., New York, 1938. Price $7.00.

This is a translation of a revised second edition by the author, dealing with methods of qualitative analysis by spot tests with inorganic and organic applications. It results from 17 years of work. Spot tests are

so simply carried out that the method has become popular. This book deals with apparatus; tests for the metals divided into the hydrogen sulphide, ammonium sulphide, ammonium carbonate, and alkali groups; tests for acids; systematic analysis of mixtures; organic tests, divided into elements, characteristic, and specific organic groups; applications of spot reactions in testing for various metals and other elements in minerals, ores, alloys and numerous natural and manufactured products. It concludes with a chapter with a tabular summary of sensitivities of spot tests.

It is a book that will be of inestimable value to geologists, chemists and physicians.

BOOKS RECEIVED.

J. D. BATEMAN

This Earth of Ours. V. T. ALLEN. Pp. 364; figs. 268. Bruce Pub. Co., Milwaukee, 1939. Price, $3.50. *The old story of physical and historical geology retold in non-technical terms for the lay reader; many erroneous statements, and others that few beside the author would agree with; many striking illustrations and diagrams.*

Die jungvulkanischen Gold-Silber Erzlagerstätten des Karpathenbogen. A. KELKE. Pp. 175; figs. 48; pls. 33. Arch. für Lagerstätten Forschung, 66. Prussian Geol. Surv., Berlin, 1938. *A careful study of 'young volcanic' precious metal deposits, with detailed microscopic descriptions of 23 ore and gangue minerals; unusual ores, well illustrated.*

Applied Geophysics, in the search for minerals. A. S. EVE AND D. A. KEYS. 3d Edit. Pp. 316; figs. 112. Cambridge Univ. Press and Macmillan Co., New York, 1938 (1939). Price, $4.25. *A thorough revision and bringing up to-date of a well known standard text and reference; a new chapter on recent advances, particularly resistivity; good reference book.*

Elements of geology, with reference to North America. W. J. MILLER. 2d Edit. Pp. 524; figs. 367. Van Nostrand Co., New York, 1939. Price, $3.50. *Rather thorough revision of 1931 edition with enlargement, inclusion of block diagrams and many new pictures in addition to elimination of worthless ones; particular revision of the sea, Archeozoic, Proterozoic and Cenozoic eras; a greatly improved book.*

Chemical Composition of the Earth's Crust in East Indian Archipelago: I. Spectrographic determination of elements according to arc methods in range 3600–5000 A; II. Rarer elements in the Netherlands East Indies. W. VAN TONGEREN. Pp. 181; figs. 14. Centen Pub. Co., Amsterdam, 1939. Price, 4.50 Fl. *Apparatus, technique, exposures, determination of elements according to periodic system, and rarer elements present; many valuable tables.*

Geological Publications, Venezuela, 1938. Pp. 272; figs. 21; maps. Bol. Geol. y Mineria., Tom. 2, Nos. 2, 3, 4, April, July and October,

1938. Caracas. *Series of papers on Venezuelan geology, dealing principally with stratigraphical problems in Venezuela and Trinidad presented before the Second Venezuelan Geological Congress, San Cristóbal; contains a synoptic chart of the nomenclature of clastic sedimentary rocks with English equivalents; English and Spanish editions.*

Geology and Ground-water Resources of the Snake River Plain in Southeastern Idaho. H. T. STEARNS, L. CRANDALL AND W. G. STEWARD. Pp. 268; figs. 16; pls. 25; maps, 6. U. S. Geol. Surv. Water Sup. Paper 774, 1938. Price, $1.25. *Contains map showing contours of the water table; large springs in Snake River canyon are result of canyon intercepting a parallel series of former canyons of the river that are now filled with permeable lava and serve as channels for ground water.*

Geology of the Sandy Lake Area, Ontario. J. SATTERLY. **Geology of the North Spirit Lake Area.** J. D. BATEMAN. **Recent Developments in the Favourable Lake Area (Geology of Berens River Mine).** J. D. BATEMAN. Pp. 100; figs. 15; pls. 35; geol. maps, 2. Ont. Dept. Mines, Ann. Rept., vol. 47, pt. 7, 1938, Toronto, 1939. *Geology and gold occurrences in Archean schist belts of remote northwestern Ontario.*

Sur la composition et l'attribution au Jurasso-Crétace de la série schisteuse du Maio Lidi (Cameroun septentrional). RENÉ VAN AUBEL. **Sur les roches du soubassement de la région entre Bangui et le Cameroun.** V. BABET. Pp. 43; geol. map. Pub. du Bur. d'Études Géol. et Min. Coloniales, No. 10, Paris, 1939. Price, 15 fr. *Brief, scholarly reports on some geologic features of French Equatorial Africa.*

Geology and Oil and Gas Resources of Logan, Gove and Trego Counties, Kansas. K. K. LANDES AND R. P. KEROHER. Pp. 45; figs. 8. Kansas Geol. Surv., Min. Resources Circular No. 11, Lawrence, 1939.

Senonsstratigraphie im Durchbruch der Weichsel zwischen Ráchow und Puławy in Mittelpolen. Władysław Pozaryski. Pp. 94; figs. 2. Inst. Géol. de Pologne, Bull. 6, Warsaw, 1938. *Stratigraphy and correlations of part of central Poland; German and Polish.*

The Gold Occurrences Southwest of Pietersburg. J. WILLEMSE. Pp. 38; pls. 4; maps, 3. Union of S. Afr., Geol. Surv. Div., Geol. Ser. Bull. 12, Pretoria, 1938. Price, –/6. *Structural control of lode gold deposition in rocks of Swaziland system and Old Granite, Transvaal.*

Die Verteilung einiger Wichtiger Skandinavischer Leitgeschiebe in einem teile Polens. V. MILTHERS UND KELD MILTHERS. Pp. 27; map; tables. Inst. Géol. de Pologne, Bull. 5, Warsaw, 1938. *Statistical study of Scandinavian rock types in the glacial drift of part of Poland.*

SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of papers to be presented at the Summer Meeting in conjunction with the Geological Society of America, Cordilleran Section, Berkeley, California, August 8–10, 1939.

DRY POLISHING OF MINERAGRAPHIC SPECIMENS.

HORACE J. FRASER AND R. VON HUENE.

Polishing by a dry method was investigated with the hope of obtaining a satisfactory polished surface more quickly than by the lead lap method and with less relief than by cloth polishing.

The chip is prepared in the usual manner. A final grind on a bronze-lead lap with water and 800 crushed corundum gives a uniform matte surface free from deep pits. Hand polishing is done on an 8 inch horizontal iron lap, running at approximately 1500 R.P.M., covered with special paper towelling or brown paper, and held by a metal band. The abrasive, either commercial black magnetic rouge or tin oxide, is applied dry and run in with a steel disk. The average specimen requires 5 to 20 minutes for a scratch free surface with only moderate relief. The relief can be practically eliminated by using a Celotex or other pressboard lap. The abrasive is best applied in a cementing mixture of celluloid and acetone and then dried. A mechanical head, driven by friction at the lap surface may be used. A polishing period of 10 to 30 minutes gives a relief free, scratchless surface on most ores. Dry polishing requires a minimum of equipment. It is particularly efficient on hard minerals. A few soft minerals such as chalcocite and bornite react with rouge to form a coating which is easily removed by touching up on a rubber finishing lap. The method has given satisfactory results during the past three years.

SOME FEATURES OF QUICKSILVER DEPOSITS IN AND NEAR LAKE COUNTY, CALIFORNIA.[1]

CLYDE P. ROSS.

The deposits in the Mayacmas and Sulphur Bank districts illustrate the genesis of cinnabar deposits in general. Those of the Mayacmas district are Pliocene (?) and those of Sulphur Bank are so recent that deposition of metallic minerals has not yet ceased. Thus cinnabar deposition has continued intermittently for a long time.

The mineralogy is simple. Many individual seams are lined solely with cinnabar, but dolomite and silica may occur. Cinnabar rarely forms by

[1] Papers thus indicated are published by permission of the Director, Geological Survey, U. S. Dept. of Interior.

replacement. Hydrocarbons, as usual, are widespread in the ore. They constitute one of the puzzling but fundamental characteristics of cinnabar deposits. Nickel minerals in small amount are conspicuous in the Mayacmas district and are presumably derived from the serpentine. Although cinnabar has been reported in silver lodes in neighboring areas, here as elsewhere the cinnabar lodes are almost free from other metals, a fact that accords with the concept that the solutions had traveled so far from their magmatic source as to be greatly modified.

In spite of differences in detail, the deposits are structurally alike in that the ore is mainly in places where fractures or other openings are especially plentiful, such as the vicinity of serpentine contacts. This is in keeping with the fact that cinnabar lodes are rarely persistent in depth. Structural traps have aided locally, not universally, in the formation of ore shoots.

GENETIC CORRELATION OF CINNABAR AND SOME GOLD–SILVER DEPOSITS.

HORACE J. FRASER.

Cinnabar deposits are a rather unique type of almost monomineralic sulphide mineralization characterized by shallow depths of formation and probably very low temperatures. Gold-silver deposits of the near surface type show a much greater variety of associated minerals and structural types. A mineralogic and spectrographic investigation of these two types shows a remarkable similarity in the metalliferous elements present. Western cinnabar deposits contain a relative concentration of the following heavy elements—iron, chromium, manganese, copper, zinc, lead, cobalt, nickel, germanium, arsenic, antimony, gold and silver. Of these, copper, silver, lead, cobalt and germanium are shown by quantitative spectrographic analyses to be present, apparently as solid solutions, in the cinnabar in amounts considerably exceeding those in the adjacent wall rock. The gold-silver deposits commonly contain iron, copper, lead, zinc, gold, silver, arsenic, antimony and mercury in amounts sufficient to form characteristic minerals. Elements present, not in recognizable minerals but probably existing in solid solution, include cobalt, manganese, chromium, gallium, nickel and molybdenum. The presence in many of these gold-silver deposits of cinnabar or even of free mercury is particularly significant. In some, the total quantity of mercury considerably exceeds that of gold. Silicification of the wall rock and dispersion of cinnabar and gold in quartz are likewise characteristic of both types. It appears that the solutions, forming gold-silver deposits of at least the very near surface type and cinnabar deposits, differ chemically only in the quantitative proportion of the elements present.

PRELIMINARY NOTES ON THE RELATION OF PHILIPPINE MINING DISTRICTS TO THE STRUCTURAL HISTORY OF THE ARCHIPELAGO.

EDWARD WISSER.

Present-day knowledge of rock formations, structure and geologic history of the Philippine Archipelago is summarized, with special refer-

ence to the Miocene Revolution, which was marked by intense deformation and intrusion, culminating in the formation of gold-quartz veins, the source of the Philippine gold production today. In northern Luzon (Baguio district) the late Miocene deformation was a reflection of east-west compression. The Miocene sediments are folded along north-south axes; major intrusions connected closely in time with the diastrophism have north-south trends. The fracture pattern at Baguio dates from this period; analysis of the fault movements indicates plainly shortening of the deformed area in a direction roughly east-west, elongation north-south. Evidence is produced to show that the fracturing took place toward the end of the period of regional east-west compression, and that the vein-matter that filled the fractures to form the Baguio veins came in while east-west compression still operated.

The other principal gold districts of the Philippines lie along the Philippine Fault Zone, a zone of vertical faults with horizontal displacements, extending southeastward from a point on the east coast of Luzon about due east of Manila, through the islands of Burias, Masbate and Leyte and probably to the Surigao district, at the northeast tip of Mindanao. Districts along this zone include Paracale, Masbate and Surigao. Instead of east-west compression, a regional shearing stress operated within the Philippine Fault Zone. The shearing couple acted roughly in a horizontal plane, and in a counterclockwise sense: the ground southwest of the fault zone moved southeast with respect to the ground northeast of the fault zone. But as at Baguio, horizontal fault movements accompanied the introduction of vein-matter and gold in the districts of the Philippine Fault Zone; such movements were however reflections of regional shearing stress instead of simple compression as at Baguio.

An attempt is made to integrate the two tectonic provinces into a logical whole, and to draw generalizations concerning the connection of diastrophism, intrusion, mineralization and the localization of ore shoots.

GEOLOGICAL OCCURRENCE AND PRACTICAL RELATIONS OF WATER, GAS AND OIL ENCOUNTERED IN DRIVING THE CLAREMONT TUNNEL THROUGH THE BERKELEY HILLS.

GEORGE D. LOUDERBACK.

The Claremont tunnel, 18,060 feet long, cuts transversely through the Berkeley Hills about 1,350 feet below the summit of the range, and intersects all of the characteristic formations of the range except those high in the summit region syncline. A geologic cross section along the tunnel line will be used as a basis for explaining the distribution of the fluids and the practical difficulties encountered. No water-bearing strata were found in the Jurassic, Cretaceous or Miocene formations although a certain amount of water entered the tunnel from all of these along small faults and shear zones. The Pliocene sediments yielded small flows and seepages from certain conglomerate layers and in places along minor faults, but in general the fine sediments were remarkably dry. The main

water flows in the tunnel came from, (1) Pleistocene stream beds along the Haywards fault zone, (2) the crush zone of the Wild Cat fault, and (3) the Pliocene volcanics. Each of these produced its own characteristic difficulties and problems.

Hydrocarbon gas was found in the Cretaceous, not sufficient to vitiate the atmosphere for breathing, but at one point gave rise to an explosion. Light oil seepages (accompanied by more or less gas) were encountered in the freshwater Pliocene and gave rise to several fires, one of which was quite serious. Theoretically this oil and gas originated in the Claremont marine bituminous shales, but no free gas or oil was encountered at any point along the bituminous shale section.

STRUCTURAL CONTROL AND FORM OF ORESHOOTS IN THE SOUTHERN APPALACHIAN GOLD DEPOSITS.[1]

C. F. PARK, JR.

About 1,500 deposits that have yielded some gold are known along the eastern front of the Appalachian Mountains and the Piedmont Province from Great Falls on the Potomac to east-central Alabama.

Metamorphic igneous and sedimentary country rocks of pre-Cambrian or Paleozoic age are intruded by granitic masses of late Paleozoic (?) age. The rocks are cut by northeastward-trending sheared zones or distributed faults and northwestward-trending tension cracks and faults. The sheared zones are as much as 200 feet wide and many have been followed more than 10 miles along the strike. They generally dip $+75°$ and are conspicuously fluted.

The lodes were formed late in the Appalachian revolution and before the Triassic period. They are of two intergradational types, veins and mineralized sheared zones, both mainly of replacement origin. The lode material is principally quartz with pyrite or pyrrhotite and small amounts of other minerals.

Oreshoots are localized in shattered places in the brittle rocks rather than in the shaly or schistose ones. Individual shoots are formed

(1) where lodes roll either on the strike or dip. The shoots are tabular or cylindrical. Examples, Gold Hill, N. C., Rudisil, N. C.;

(2) where lodes are cut by zones of sheeting or tension cracks. The resulting shoots are tabular, cylindrical, or in pods connected by stringers. Examples, Hog Mountain, Ala., Battle Branch, Ga.;

(3) where fluting has permitted circulation of mineralizing fluids. The shoots are cylindrical. Examples, Vaucluse, Va., and Findley, Ga.;

(4) where lodes enter schistose rock from a more brittle material (damming). Example, Hog Mountain, Ala.;

(5) where schist walls are "rifted" and quartz stringers are formed between layers. Stringer leads. Examples, Cherokee, Ga., White County, Ga.;

(6) where breccias have been extensively replaced. Walls are determined by assay. Examples. Haile, S. C., and Howie, N. C.;

(7) where mineralizing fluids have penetrated the weaker, shaly strata. Irregular pockets. Examples, Laird, Va., Young American, Va.

STRUCTURAL CONTROL OF ORE DEPOSITION: THE EFFECTS OF MINERAL SEQUENCE.

CARLTON D. HULIN.

It is increasingly recognized that minerals of hydrothermal ores are deposited in sequence. It is less commonly appreciated that this depositional sequence is likewise a sequence of introduction of elements. The common metals are introduced in the order: iron, zinc, lead, copper, silver, gold. Although the relative time of appearance of these elements is essentially fixed for all ores, the time of persistence and concentration of each respective metal in the solutions varies radically in different cases.

The acid elements combining with these metals likewise are introduced in definite sequence: oxygen, sulphur, arsenic, antimony. Again the relative time of appearance is fixed, but the time of persistence in the solutions and the concentration may vary radically. Furthermore these acid elements as a group are not in fixed sequence relative to the metals.

The mineral sequence thus is controlled not only by the time of appearance of the respective elements, metallic and acid, but also by the combination of elements and their relative concentrations in the solutions at progressive stages. Minerals of tin, tungsten, molybdenum, bismuth, are recognized as being erratic in their time relation to the more common metals. These minerals are definitely coincident in time with the main period of quartz deposition.

In most ores the period of deposition of quartz and associated minerals (Group I) precedes but overlaps the period of deposition of the common metallic minerals (Group II). Deposits are known however where Group II is later than and separated in time from Group I; where Group II occurs at the start of Group I, overlapping it; and where Group II precedes Group I without overlap.

It must be concluded that during mineralization Group I (SiO_2, W, Sn, Mo, Bi) is independent of Group II (Fe, Zn, Pb, Cu, Ag, Au, etc., and associated acids), any time relation, or the absence of either group, being possible.

If ore shoots are regarded as being controlled in position by the location of permeable openings existing at the time of the presence of the valuable metals in the mineralizing solutions, then the relative times of Group I and Group II will in the several possible cases produce ore shoots of entirely different character and localized by entirely different structure.

MINERAL DEPOSITION AT STEAMBOAT SPRINGS, NEVADA.

VINCENT P. GIANELLA.

Steamboat Springs has long been of interest to geologists because of the minerals now being deposited from the hot waters. The water issues at temperatures up to 95° C. and has a high content of sodium chloride and silica but is low in calcium. The large deposit of sinter is composed largely of silica although, in some areas, a small carbonate content has been reported. Several sulphide minerals have been found in the sinter, and cinnabar has been mined to a limited extent. Many wells have been drilled to insure a more plentiful supply of steam and hot water. After

a time, sometimes within a week, the flow is seriously impeded due to mineral deposits forming in the casings and this material must be constantly removed. Eventually the wells cease to flow and others are bored. Examination of this deposit shows that it consists of practically pure calcium carbonate and not silica as might be expected from the nature of the water and the high silica content of the sinter. A well bored at the south end of the sinter terrace ejected a considerable quantity of metastibnite. Another, about one and one-half miles to the north, near the end of the sinter area, produced much stibnite in slender, matted, needle-like, crystals. Wells drilled farther north, beyond the sinter deposit, have encountered hot water and steam in alluvial fan material containing minute crystals of pyrite and stibnite.

SCIENTIFIC NOTES AND NEWS

H. C. GUNNING has resigned from the Geological Survey of Canada to join the staff of the Department of Geology, University of British Columbia. He will leave Ottawa for Vancouver in August.

H. RIES, Professor of Geology, Cornell University, is retiring after having served as head of the department for twenty-three years. C. M. NEVIN, Professor of Geology, has been appointed chairman.

M. B. LIGHTFOOT, director of the Geological Survey of Southern Rhodesia, is now president of the Geological Society of South Africa.

J. K. GUSTAFSON, for the past three years in charge of a detailed investigation of the Broken Hill ore deposits for North Broken Hill, Ltd., Broken Hill South Ltd., and Zinc Corporation, Ltd., left Australia April 10 to return to the United States via England and Europe.

E. T. MELLOR has been awarded the Draper Memorial Medal by the Geological Society of South Africa.

N. M. FENNEMAN, Professor of Geology at the University of Cincinnati and past President of the Geological Society of America, gave a series of exchange lectures on Appalachian History, the Appalachian Plateau, the Great Lakes Section and the Infancy of Geology at the University of Kansas during the week of April 17. K. K. LANDES will give a return series at Cincinnati this fall.

H. S. GALE is carrying out professional work in South Africa.

PATRICK MARSHALL, geological advisor for the New Zealand government, is president-elect of the Australian and New Zealand Association for the Advancement of Science.

The Seventh Annual Conference of the ILLINOIS-INDIANA PETROLEUM ASSOCIATION was held in Robinson, Illinois on June 3. After a program of interesting papers on oil and gas possibilities, producing practices and geological data, the annual Oil Men's golf tournament was held at the Crawford County Country Club.

The AMERICAN GEOPHYSICAL UNION held their 20th Annual meeting at Washington, D. C., April 26–28. The sessions on geology, meteorology, terrestrial magnetism, oceanology, vulcanology and hydrology were unusually interesting and well attended. The meeting concluded with a symposium on geophysical prospecting.

R. MURRAY-HUGHES returned from Jugoslavia to England and then left for South America.

DAVID GALLAGHER of Brookline, Massachusetts, has been awarded the Samuel Franklin Emmons Memorial Fellowship for the academic year 1939–1940.

P. H. TRUSCOTT has left England for Northern Rhodesia.

W. B. JONES is director of the Department of Conservation at Montgomery, Alabama.

The GEOLOGICAL SOCIETY OF AMERICA is presenting the following radio addresses through the National Broadcasting Company: April 24, Submarine Canyons by Paul A. Smith; May 1, Shifting Ocean Levels by Douglas W. Johnson; May 8, The Role of Minerals in the Present International Situation by C. K. Leith; May 15, Geology in the Search for Petroleum by W. B. Heroy; May 22, Origin of Mountains or How Mountains Rise by C. R. Longwell; May 29, Geology in Engineering by C. P. Berkey; June 5, New Uses for Old Minerals by E. H. Krause; June 12, The Geological Meaning of Deep Earthquakes by L. B. Slichter.

D. F. HEWETT of the U. S. Geological Survey was a recent visitor at Yale and Harvard.

The AMERICAN INSTITUTE OF MINING ENGINEERS will hold a summer meeting in San Francisco, July 10–13. There will be technical sessions and excursions to nearby mineral districts.

CHARLES E. LOCKE has been appointed acting head of the department of Mining Engineering at M. I. T. to succeed W. Spencer Hutchinson.

The U. S. GEOLOGICAL SURVEY plans investigations of strategic minerals in the United States this coming field season, provided the strategic minerals bill passes Congress. Investigations on the occurrences, quantities and quality will be made on manganese, tin, nickel, chrome, mercury, tungsten, antimony and others in Alaska, Washington, Oregon, Wyoming, Idaho, California, Nevada, Arizona, Utah, New Mexico, S. Dakota, Virginia and the Carolinas.

WALDEMAR LINDGREN has returned to Brooklyn from Florida, where he has been recuperating from an illness.

A new drainage tunnel will be started at Cripple Creek one thousand feet below the Roosevelt tunnel, which will be 32,000 feet long.

J. J. BEESON, geologist of Salt Lake City, is directing exploration operations at the Tintic gold mine, Eureka, Utah.

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